DOCUMENT RESUME

ED 266 941	SE 046 453

AUTHOR	Layton, David, Ed.
TITLE	Studies in Science Education, Volume Nine, 1982.
INSTITUTION	Leeds Univ. (England). Centre for Studies in Science Education.
PUB DATE	82
NOTE	183p.; For volumes 4 and 6 in this series, see respectively ED 142 390 and ED 178 310.
PUB TYPE	Collected Works - Serials (022) -- Information Analyses (070) -- Reports - Research/Technical (143)
JOURNAL CIT	Studies in Science Education; v9 1982
EDRS PRICE	MF01/PC08 Plus Postage.
DESCRIPTORS	Annotated Bibliographies; Demonstrations (Educational); Elementary Secondary Education; *Females; Mathematics Education; Policy; Preservice Teacher Education; *Science Education; *Science Instruction; *Secondary School Science; Technology
IDENTIFIERS	Great Britain; Mathematics Education Research; *Science and Society; *Science Education Research; Science Policy

ABSTRACT

Studies in Science Education is an international review of research for all who are interested in the educational dimensions of science. This issue contains these articles: "Teaching about Science, Technology and Society at the Secondary School Level in the United States. An Educational Dilemma for the 1980s" (Mary C. McConnell); Science Education for Citizens: Perspectives and Issues I: "Science, Technology and Society: Issues for Science Teachers" (P. James Gaskell); Science Education for Citizens: Perspectives and Issues, II: "Science and Technology Policy and the Democratic Process" (Dorothy Nelkin); "Men's Science, Women's Science or Science? Some Issues related to the Study of Girls' Science Education" (Catherine A. Manthorpe); "Girls and Mathematics and Science. An Annotated Bibliography of British Work (1970-1981)" (Donna M. Kaminski); and "Demonstration versus Small Group Practical Work in Science Education. A Critical Review of Studies since 1900" (R. M. Garrett and I. F. Roberts). Also included is a research study dealing with the early experiences of young teachers at the beginning of their career ("Training Teachers to Cope with the 'Reality Shock'" by T. Wubbels and others), a supplementary list of theses and dissertations submitted for higher degrees in British universities (1979-80), and a book review. (JN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED226941

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
☑ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

STUDIES IN SCIENCE EDUCATION

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
James Wrigley
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

SE 046 453

2

STUDIES IN SCIENCE EDUCATION

Editor David Layton
Centre for Studies in Science Education
University of Leeds

Editorial Advisory Board

Professor Peter J. Fensham	*Faculty of Education, Monash University, Australia*
Dr. Gareth Howell	*Deputy Education Adviser, British Council Division, British High Commission, New Delhi*
Dr. F. R. Jevons	*Vice-Chancellor, Deakin University, Geelong, Australia*
Professor Kevin Keohane	*Rector, Roehampton Institute of Higher Education*
Dr. Gerhard Schaefer	*Abteilung Biologie, Institut für die Pädagogik der Naturwissenschaften, Keil*

Annual subscription:	U.S.A. $11 plus $1 postage
(including postage)	U.K. and elsewhere overseas £4.50 plus 50p postage.

Remittances from overseas countries other than U.S.A. should be in sterling. Cheques, etc., should be made payable to 'Studies in Education Ltd'., and crossed.

Enquires about subscriptions and advertising should be addressed to:
Studies in Education Ltd., Nafferton, Driffield, East Yorkshire YO25 0JL

© Studies in Education Limited

ISSN 0305-7267

Studies in Science Education 9 (1982), 1-32

Teaching about Science, Technology and Society at the secondary school level in the United States. An educational dilemma for the 1980s

MARY C. McCONNELL
School of Education, Portland State University, Oregon, U.S.A.
(Formerly Staff Associate, B.S.C.S., Boulder, Colorado)

Within the past decade in the United States there has been increasing recognition that the definition of science education needs to be expanded to include social issues related to scientific development and to incorporate relationships between science and technology as well as education about science and technology. Such recognition goes back a decade when in 1971 the Advisory Committee for Science Education made a number of recommendations to the National Science Foundation (Advisory Committee for Science Education, NSF, 1971). The Report of the Committee stressed one overriding goal for the next decade: 'to educate scientists who will be at home in society and to educate a society that will be at home with science'. The Report made by the Committee included the following recommendations:

- 'Increased emphasis on the understanding of science and technology by those who are not, and do not expect to be, professional scientists and technologists'.
- A shift, in part, from 'the traditional discipline orientation to interdisciplinary approaches centred upon problems faced by informed citizens'.
- 'Science and technology have essential contributions to make in the formulation and solution of critical societal problems'.
- 'An understanding of science and technology can and must be extended through education to all of the population'.

The Committee saw the need for a large common body of knowledge and experience related to science and technology, and their impact, which would be shared by all citizens.

THE PRESENT CRISIS IN SCIENCE EDUCATION IN THE UNITED STATES

More recently professional science educators and others concerned with the state of science education in the United States have identified a crisis in science education. What is the nature of that crisis?

The science curriculum improvement projects of the 1960s and 1970s failed to generate the results expected of them in terms of improvement of scientific literacy for the general public. With the onset of economic pressures, increases in school taxes, declining school enrolments, the deglamorizing of science and technology, decline in the hiring of recently educated teachers, and other factors, criticism of American education has grown to a level unprecedented in recent years. Science teaching has not escaped the onslaught of public criticism. Science enrolments are down, student achievement in some grade levels is on the decline (NAEP, 1978), and morale of teachers is low. There is concern among scientists, engineers, educators, and government agencies that a continuation of these educational deficiencies can only be detrimental to the national interest.

Between 1970 and 1980 various citizen, science, and education groups have in various ways analyzed the present status of science education. Several of these reports are summarized below.

National Science Foundation Status of Science Education Studies. To determine the status of science (along with mathematics and social science) education across the United States in the late 1970s, the National Science Foundation supported three concurrent studies: a literature review (Helgeson *et al.* 1977), a national survey (Weiss, 1977), and a series of case studies (Stake and Easley, 1977). Next, the National Science Foundation invited nine professional organizations to review the studies and to make recommendations from them (NSF, 1980). Throughout the reports from these organizations, there was distress expressed concerning the 'back to the basics' movement and its effects on science education. Science is perceived as 'non-basic'. Secondary school science teaching is textbook dominated. Little use of inquiry-oriented teaching strategies was evident. The predominant instructional method at all grade levels was lecture-discussion.

Most reviewers offered few recommendations for improvement of science teaching in the future, with the exception of the Panel on School Science of the National Academy of Sciences, National Research Council. Recommendations from this panel included the establishment of locally based resource centres to provide inservice training for science and mathematics teachers as well as development and distribution of low-cost kits of science and mathematics materials. The panel argued that literacy in science as an objective of American education is as urgently needed as the basic skills of reading, writing, and arithmetic.

The reviewing groups also noted that secondary school science education lacks a sense of direction and a theory and philosophy to provide guidance to curriculum development and instruction. What students should learn also remains unclear. A further examination of the goals and purposes of science teaching is needed, especially in terms of what non-specialists need to know.

National Science Foundation and Department of Education Joint Report on Science and Engineering Education (Hufstedler and Langenberg, 1980). In response to a February 1980 request from President Carter, the National Science Foundation and the Department of Education prepared a joint report on the condition of science and engineering education in the United States. The report focused on two major goals of such education: the basic scientific and technological education of all citizens; and the production of scientists, technicians, and engineers. The study reported the proliferation since 1960 of federally supported science curriculum projects, followed by a trend away from development and use of such programs. Except for biology, few science courses currently use the products of national curriculum programs. However, the impact of the national programs can still be seen in the programs offered by commercial publishers. Many of the science programs presently available were designed for the college-bound student.

> 'The emphasis is heavily on the pure "structure of the discipline" form of science. Very little in the content of courses provides information related to personal or societal problems, about technology and what engineers do, or to vocational relevance except to those students interested in professional science careers'. (Hufstedler and Langenberg, 1980)

The report emphasizes the widening gap between high school students who are headed for careers in science or engineering and who are achieving in their present science courses, and those high school students who are not interested in science (whether or not they are academically oriented otherwise) and whose achievement in science is less than in previous years. These students are taking few classes in science. The report also emphasizes the needs of the country in technology.

The report recommends that precollege science courses be more 'directed toward personal or societal problems involving science and technology' in order to provide students with a better basis for understanding and dealing with science and technology as citizens, workers, and private individuals. Other recommendations for the improvement of science teaching include:

- the need 'to prepare students to understand and use the new electronic aids to the human mind'.
- developing curriculum materials that focus on the science and technology basis of essential national problems such as energy, natural resources, and health.
- 'Individualized, interactive instruction in science, mathematics, and engineering for students at all levels, ranging from drill and practice to the simulation of complex problem situations'. (NSF, 1980.)

National Science Teachers Association (1978). A NSTA study identified the following factors as related to the crisis in science teaching: 1) decline in student population; 2) increasing diversity among students; 3) decline in local and national funding; 4) loss of public confidence in science and public education; 5) decline in science course enrolments; 6) unfavourable student attitudes toward schooling; 7) science curricula unsuited to current needs; 8) inappropriate pre-service and inservice teacher education; 9) unionization of teachers; 10) mandated accountability.

Status Study of Graduate Science Education in the United States, 1960-1980 (Yager, 1980). One hundred and fifty college and university faculty members representing all the science education research centres in the United States identified the following factors as contributing to the crisis in science education: 1) general anti-science tenor in the United States; 2) declining enrolments in science courses; 3) diminishing financial support; 4) lack of leadership in science education; 5) lack of a theoretical base to guide research; 6) poor quality of teacher education programs; and 7) inappropriate school science curricula. A second part of the status study included pre-college science teachers, inservice supervisors, department chairpersons, graduate students in science and college science educators (30 persons in each category). These respondents identified the following factors as contributing to the crisis in science teaching: 1) confusion about goals and objectives; 2) lack of vision and leadership in schools and universities; 3) public apathy toward science; 4) limited budgets; 5) poor quality of teacher education; 6) limited scholarly dialogue between educational researchers and practitioners; 7) declining enrolments; and 8) lack of a theoretical base for education in the sciences.

The Advisory Committee for Science Education of the National Science Foundation's Report to the National Science Board (1980). The Advisory Committee for Science Education of the National Science Foundation in its report to the National Science Board (1980) noted that 'at the very time that the strong federal effort in support of science is having its major impact, education of our citizenry to understand and cope with this impact is declining in effectiveness'. The report suggested that new perspectives are needed for the teaching of science which respond to the 'new problems in the changing relationship between science and technology and the larger society' and which make it possible for citizens to understand their role in modern life as well as to facilitate the use of science and technology in matters of personal choice and public policy.

In summarizing these studies, it appears that over the past decade the system of science education in the United States has come to be out of harmony with the changing conditions of science, the national interest and well being, and the personal needs of individuals for living and effectively participating in a modern scientific/technological/industrialized culture. Something is amiss in school science education. Members of the teaching profession are not clear about the purposes or goals of science teaching. Science is not considered an important subject in the general education of citizens with the result that state boards of education mandate only a token course, or require none, in the precollege education of students. In short, a crisis exists in science education in the United States.

NEEDED: A NEW DEFINITION OF SCIENCE EDUCATION

Changes in the relationship of science, technology, and society and their impact on human affairs indicate the need for a new definition of science education. The social, economic, and political circumstances of today's world are largely a consequence of achievements in science and technology. This is not a new relationship; however, the context of problems today is quite different from that of even a decade ago. The global character of science and technology influences national policies and alters social history. Yet science is usually taught as if it were not connected with social change or even a part of cultural heritage. A central task in the 1980s for science teaching is the development of a rationale and philosophy that is consistent with the current status of science and technology and responsive to science/technology/society issues and problems affecting nations throughout the world.

Numerous prestigious panels and committees are pointing to the need for education about the interface of science, technology, and society. In 1980, The National Research Council sponsored a series of panels on educational policies in science and engineering. Implicit in the discussion of panel members was a recognition of the interconnectedness of science, technology, society, the economy, and education for a nation's well-being and security (National Research Council, 1980). The full use of human resources including those of women, minority groups, and the talented is needed to advance science and technology. In order to facilitate this advancement, a high level of scientific literacy is necessary, including familiarity with scientific concepts and the tools of technology.

The Exeter Conference on Secondary School Science, a week long conference, involving thirty-eight secondary school teachers from across the United States and ten specialists in science, recommended that societal and ethical consequences of modern science and technology should become a part of the science curriculum. 'The conferees agreed that what is required is an infusion into existing programs of materials that place the study of science into a societal context. The material must give young people opportunities to experience, with guidance, the sifting and weighing of evidence derived not only from the science laboratory but also from the avenues of information that are routinely available to the public, such as the media and the local library. Students must be confronted with problems which, unlike those raised in the usual science programs, do not lend themselves to simplistic, uniquely "correct", answers. Real social issues give rise to a variety of possible solutions, each providing some benefit but only at some cost'. (Aaronian *et al.* 1980)

Project Synthesis, a two-year study of 'the countenance of science education' based on the three national status studies of science teaching supported by the National Science Foundation, resulted in the following recommendations (Harms and Yager, 1981):

1. 'A major redefinition and reformulation of goals for science education; a new rationale, a new focus, a new statement of purpose are needed. These

new goals must take into account the fact that students today will soon be operating as adults in a society which is even more technologically-oriented than at present; they will be participating as citizens in important science-related societal decisions. Almost total concern for the academic preparation goal as is currently the case is a limiting view of school science'.

2. 'A new conceptualization of the science curriculum to meet new goals; redesign of courses, course sequences/articulation, and discipline alliances are needed. The new curriculum should include components of science not currently defined and/or used in schools. Direct student experiences, technology, personal and societal concerns should be foci'.

At the university level, the involvement of ethics and values in the practice of science and technology has become a growing concern of a variety of scholars and practitioners. A national survey to determine the extent of academic activities in the field of science, technology, and human values in institutions of higher education, revealed that courses or programs were offered in 919 colleges or universities in 1978 (AAAS, 1978). In addition, courses or programs related to science, technology, and society; environmental concerns; health care; and contemporary moral and ethical problems related to science and technology were offered in 879 institutions (AAAS, 1978).

In the past decade, the American Academy of Arts and Sciences has examined the relationship of science, technology, and society in three issues of its publication *Daedalus* (Proceedings of the American Academy of Arts and Sciences, 1974, 1978, 1980). In an issue on 'science and its public' (1974) the growing challenge to the theoretical foundations of science and its place in society was explored by scientists, social scientists, engineers, philosophers of science, and others. Although no effort was made to achieve a consensus on the issue, several ideas were recurrent.

> 'At least until recently, the relationship between man and nature which has evolved from modern science has been more or less tacitly understood (at least in the western world) in about the same way among those who have received any substantial education. In this relationship, science was thought to have two largely beneficial functions: first, to provide a method for gaining a deeper understanding of the links between man and wider nature, and in this way to make him intellectually (and perhaps spiritually) more exalted; and second to help him transcend his physical limitations, e.g., by paving the ground for medical and other technological development'. (Proceedings of the American Academy of Arts and Sciences, 1974)

However, since the close of World War II the intellectual character of science has been increasingly challenged. 'Whereas the goals of science are largely derived from the structure of science itself, those of technology frequently derive from political, economic, and other external affairs'. Science claims a kind of morality and justification intrinsic unto itself; technology is often judged in relation to outside values. Since technology is the least remote from the public, people tend to see science as primarily a collection of practical tools that are a part of technology. Few people are interested in science as an intellectual, aesthetic, or methodological enterprise. 'The overwhelming majority of the public seems to confuse science and technology and sees science in a very technological, instrumental light'.

The authors of the 1978 *Daedalus* issue on 'limits to scientific inquiry' in various ways recognize that research in science has acquired a public or social dimension in addition to the production of new knowledge (Proceedings of the American Academy of Arts and Sciences, 1978). Not only the scientific merit of research is of concern but also its social merit. Traditional views of science and the scientific enterprise are in the process of change. There is a growing public interest in science policy as well as a growing awareness of this public interest on the part of the scientific community. Public concerns about science are often linked with concerns about technology. Increasingly, the connections between basic research, innovation, applied research, development, technology, and social and economic progress nationally and globally are becoming 'a seamless web'. The old bargain between society and science – the acceptance by society of basic research because it is believed that it will result in social benefit – is being reexamined. 'We have in fact entered a period where old and new theories of progress in science are vigorously competing – in the minds of the public, among those engaged in the study of nature, and among scholars who study science as an activity'.

The deliberations reported in the 1980 *Daedalus* volume on 'modern technology' note that public discussions of technology are more appropriate to the nineteenth century than to the twentieth (Proceedings of the American Academy of Arts and Sciences, 1980). Older views of technology focus more on machinery than on system. A modern view of technology insists 'that it be thought of not as a collection of artifacts, however sophisticated and complex, but as a system whose social, cultural, intellectual, managerial, and political components are seen as integral to it'. We also need to recognize that the relationship of science and technology is more complexly intertwined than is often imagined. 'The connections between science and technology have become increasingly strong in the modern era of systems development and application'. Advances in technology very often bring about a rescheduling of human values, influence economic conditions, foment changes in professional education, and open new possibilities for scientific achievement.

An international organization of scholars in several social science disciplines has examined the social policy dimensions of science and technology (Spiegel-Rösing and Price, 1977). The group recognized that while studies of the interaction of science, technology, and society have yet to form a coherent discipline, they do have a background of serious academic inquiry.

> 'Never before have the economic as well as the social and ecological consequences of scientific discovery and technological innovation been so influential upon the fortunes of particular nations and upon the entire world system.

> Scientists and technologists have therefore become important contributors in the quest for economic growth and security and for the alleviation of disease, poverty, and overpopulation'. (Lakoff, 1977)

Science has become a part of social policy, and technology a part of science policy. These new relationships have brought about efforts which combine the solution of practical problems with the progress of basic knowledge in the sciences. The linkage between social processes and scientific knowledge is generating a new perspective about the place of science in society. The new emphasis in technology is how to make it more socially responsive to human needs.

Sociotechnical achievements have served to extend human capacities, for example, in fields of transportation and communication. Technology is a distinctive form of cultural activity with its own character and processes. Because technology creates new social arrangements, new forms of culture, and through culture changes in human values, it must be studied from a multi- or cross-disciplinary perspective.

During the spring and summer of 1978 the Science/Technology/ Society focus group of Project Synthesis discussed the potential goals for science education in the area of Science/Technology/Society with a number of scientists, sociologists, engineers, and science educators. They identified eight areas of concern from among the many possible with which citizens now in school will most likely be concerned during the remainder of their lives. These areas are: 1) energy; 2) population; 3) human engineering; 4) environmental quality; 5) utilization of natural resources; 6) space research and national defense; 7) sociology of science and technology; 8) effects of technological developments. They also made a series of recommendations to five groups: 1) school personnel; 2) curriculum developers; 3) educators of teachers; 4) funding agencies and policy makers; 5) the general public. Among the 27 recommendations presented are the following:

A) Textbook publishers should be encouraged to include STS (science/technology/society) materials in their texts in all areas of science.

B) Individual teachers should be encouraged to develop their own STS materials to fit into their courses where appropriate.

C) State education departments should encourage the inclusion of such materials into science courses as not only acceptable but desirable at all levels.

D) STS materials should be infused into areas other than science, such as English, mathematics, social science, and business.

E) STS clearinghouses should be formed.

F) Preservice and inservice teacher education programs must contain systematic strategies to develop teacher awareness of the importance of including STS as legitimate subject matter for study.

G) Since technology education is relatively new, certain basic questions about it need to be answered by research activities. Some of these questions are:

'What is the domain of technology education?' (There is a need for development of a taxonomy of technology topics for education).

'Of possible knowledge relative to technology, which knowledge is likely to be most useful?' (Piel, 1980).

Some states in the United States have begun to mandate technology education. The state of Pennsylvania, for example, has recently prescribed a separate technology education component as part of its state system of education. In a recent publication (undated) eighteen suggested student competencies are listed 'to provide teachers with a sense of direction for instruction concerning technology and its effect upon our daily lives'. The publication suggests that 'student achievement in understanding technology is not the sole responsibility of science education. The effects of technology often are societal, and so should be included in most subject areas'. (Division of Health, Science and Technology, Pennsylvania Department of Education, undated).

The numerous scientists, educators, and other professional persons who over the past decade have been considering what is needed in science teaching for the 1980s have implicitly been evolving a new paradigm for science education as a part of citizenship education. In this model, the role of science as an enterprise is not considered separately from the role of technology since both operate within the same framework of basic concepts and scientific principles. In addition, science is viewed not only as a form of knowledge, but also for its social role in advancing human well-being and national interests. This close link between science, technology, and society demands of scientists and technologists new ethical judgements. It also generates social, moral, and ethical issues for people as a whole. The present context of science teaching with its discipline-oriented goals taught as though science were unconnected with social institutions outside the laboratory is an inaccurate representation of the current status of the scientific and technological enterprises.

SOCIAL SCIENCE EDUCATION AND SCIENCE/TECHNOLOGY/SOCIETY

Within the context of American education, social studies/social science educators as well as science educators are concerned with the type of education under discussion. Throughout its history in the United States, social studies education has been charged with providing young people with the knowledge, skills, values, and attitudes that together comprise 'good citizenship'. The definitions of good citizenship and the learning deemed necessary for its development have changed over the years, but the basic concept that social studies/social science education is responsible for its development has remained (Barr, Barth, and Shermis, 1977).

During the 1960s, the emphasis in social studies shifted from an emphasis upon government, civics, and history as the foundation of citizenship education to teaching the structure and methods of various social science disciplines (Morrissett, 1967). By 1970, the interrelationships between the various social sciences and the need for materials which utilized concepts and methods from several social sciences was being recognized. At the same time, concern was emerging for teaching students to use social science information in participating in a democratic way of life.

There is growing recognition upon the part of social science/social studies educators that knowledge of science is becoming increasingly necessary in order to live productively in the social order. Barr, Bath, and Shermis (1977) state

> '. . . since interrelationships between science and society are becoming more and more evident, the question arises whether ecology should be included as content for the social studies, or whether even biology, zoology, and engineering should be included'.

Teaching and learning about social problems have long been an accepted part of social studies curricula in American secondary school education. Courses entitled Modern Problems, Problems of Democracy, or American Problems have been a part of the curriculum of senior high schools for several decades. Issues chosen for study represent the agenda of unfinished societal business about which future citizens in a democracy are supposed to be knowledgeable. The rationale for such courses is that an important objective of social studies education is to increase civic and societal literacy. In recent years, these 'problem' courses have begun to include issues that are science-related.

Recognizing this trend, in 1977 the National Council for the Social Studies gave autonomous status to its Science and Society Advisory Committee, with a mandate to help teachers, students, and others deal effectively with science-related social issues. The preamble to this mandate states 'The impact of science and technology on society, and of society upon science and technology, are of increasing and vital importance. Scientific and technological developments often move so rapidly that social institutions are unable to respond effectively. This gives rise to unprecedented ethical questions and societal problems and creates demands on citizens and on society for new insights and understandings' (Benne and Birnbaum, 1978). The increasing interest of social science educators in issues of science, technology, and society is evidenced by publication in 1978 of the National Council for the Social Studies Bulletin 57, *Science and Society: Knowing, Teaching, and Learning,* and by the October 1979 issue of the NCSS Journal *Social Education* devoted to 'science and technology for a global society'.

A FRAMEWORK FOR EDUCATION ABOUT SCIENCE, TECHNOLOGY, AND SOCIETY

There is a growing consensus among science educators and others concerned with education for scientific literacy that, because of shifts in the culture and changes in the interrelationships between science, technology, and society, a need exists for a new rationale or philosophical base for education in the sciences – and in certain aspects of the social sciences. Such a framework should reflect the place and meaning of modern science and technology in contemporary society. The new relationship of science as part of social policy, and of technology as part of science policy suggests that education about science/technology/society (STS) is necessary for the 1980s and beyond. What are the 'threads' that together might weave the 'fabric' of such a framework?

I. *The social context of science and technology.*

Science and technology together are major factors in contemporary life. They serve as agents of social and economic change, and also are the recipients of change. Science and technology have become intricately bound together; their borders at best are imprecise. While science is primarily concerned with the production of knowledge, technology is concerned with its use. However, today there is essentially an indivisibility of scientific and technological knowledge. Within social and economic structures they are even more closely bound together.

When considering national well-being, many of the most pressing problems and issues that must be resolved occur at the interface of science, technology, and society. Knowing *about* (generally considered a negative term among science educators) the nature of the scientific enterprise and its demonstrated strengths and weaknesses is not the same as knowing scientific concepts, but it is important today; learning some science is essential to its achievement.

Educators need to examine seriously the proposition that the working definition of science education ought to be expanded to include technology and also what would ordinarily be selected aspects of the subject matter of sociology, economics, politics, history, psychology, philosophy of science, and philosophy of technology. Such issues as basic versus applied science, the connections between science and technology, and the meaning and extent of freedom of inquiry in science require for their understanding both a fair grasp of some 'real' science and some explicit attention.

Science taught in a social context is ineffective unless based upon valid science information. Equally important is to understand what science is *about*, and what it can and cannot do. The proper use of science information requires an understanding of its validity as well as its limitations for directing social systems.

II. *Knowledge utilization.*

Traditionally a school science curriculum has consisted of a selection of facts, concepts and principles, organized into courses representing broad disciplines, such as biology, chemistry, physics, or earth science. The criterion for selection of the subject matter has been information that historically has been considered representative of a particular discipline. The primary task of the teacher has been to transmit the particular package of historically verified information to students. By using knowledge primarily of historical significance, science curriculum developers avoided problems associated with the tremendous growth of *new* knowledge. However, a new perception of the role of knowledge is taking place that has implications for the teaching of science. This is the view of knowledge as a major economic resource of a nation. The task for education then becomes one of developing intellectual skills to optimize the utilization of knowledge. The challenge now confronting science education is to link science as a knowledge producing system with society as a knowledge using system.. Technology is often the connecting link.

Developments in information technology have emphasized the importance of information processing skills in science education. A large amount of the known information about science and technology is available to anyone who can use it. Microelectronic technology for the storage, retrieval, and partial organization of information represents an extension of human cognitive capabilities. Knowledge creation, knowledge diffusion, and knowledge utilization form an endless cycle. The advent of the low cost microcomputer is expected to affect profoundly knowledge diffusion and utilization. The first commercially feasible microcomputer became available in 1975. Since then, as of the summer of 1981, about three million microcomputers had been sold in the United States alone (Shane, 1982). Many new questions are being raised as a result of the 'silicon chip revolution'; i.e., the development of an information rich society created by the microchip. For example, 'How can we strike a balance between the amount of reference material that theoretically *can* be stored and the amount *actually* needed?' 'How can we teach learners to use information carefully rather than carelessly as it becomes more abundant and more available?' (Shane, 1982)

III. *Problem-centred science curricula.*

Utilization of science knowledge to advance personal and national well-being requires students to learn in a problem-centred context. For the most part these problems should be 'real-world' problems that have science/technology/society dimensions such as those identified by the Project Synthesis STS group (Piel, 1980) or others appropriate to particular communities. A recent report to the Club of Rome suggests the need to develop participatory and anticipatory learning skills as part of general education throughout the world (Botkin *et al.*, 1979). Participatory learning emphasizes problem-detecting, problem-perceiving, and problem-formulating as well as problem-solving behaviour.

A curriculum of conclusions no longer is appropriate; it is essential to investigate and understand some of the major problems facing humanity. Some possible topics for inclusion in a problems-centred curriculum could relate to the armaments race, population growth, food demands and agriculture, economic stability, use and development of the oceans, outer space, nuclear proliferation, genetic engineering, natural resources and energy, and health care.

IV. *Logical reasoning and decision making.*

Utilizing knowledge in a social context to solve problems involves not only conceptual skills and logical reasoning but also consideration of personal and social values and projections for action. Every problem involves a condition and an action that may be a choice, a plan, a judgment, a decision, or a 'next step'. Simply gathering the facts about a science/social issue is not sufficient for effective action. There are almost always related questions: What are the risks, the trade-offs? Who wins, who loses? What is maximum and what is optimum? Anticipatory learning involves evaluation of medium-term and long-term consequences of current decisions and actions, and the invention and consideration of alternatives where none existed before (Botkin *et al*, 1979).

Public decision making by citizens in a democracy requires an attitude of attentiveness; skills of gaining and using relevant knowledge; values of which one is aware and to which one is committed; and the ability to turn attitudes, skills, and values into action. All of these steps can be encouraged if a decision making perspective is incorporated into the educational process.

V. *Ethics and values.*

Utilization of scientific and technological information in a social context usually raises questions related to values and ethics. These issues can arise from conflicts in how best to use, or whether to use, recently acquired knowledge for real-life purposes. Different perceptions by different individuals and groups about individual and societal well-being and progress are inevitable. New knowledge and new technological achievement usually alter the range of choices and alternatives open to people. Such choices often necessitate a reconsideration and restructuring of personal and social values. Unanticipated consequences of technological innovation can also result in ethical questions.

Science and technology as enterprises are increasingly confronted with issues of social value and merit, particularly in relation to practical consequences. The traditional idea that science is neutral, value-free, and insulated from question of value and ethics is for the most part no longer warranted.

The problems associated with technological development may primarily not be problems of technology. Rather, they may be problems among us and between us, problems in large measure the result of a pluralistic society in which common purpose, common values, and common images are no longer present. They are issues involving conflicts between values and goals within persons and among persons rather than conflicts between dams and people, or industry and environment. Resolution of conflict requires communication and creative problem solving to facilitate mutual understanding and effective interaction between people and groups that have different values, different images of the future, and different definitions of trade-offs and benefits and costs.

In the teaching of secondary school science, operational values associated with the scientific method of gaining knowledge can be explicitly addressed. In addition, value and ethical issues that arise when science and technology are elements of societal issues need not be avoided. Here students are not taught values, but are confronted with ethical dilemmas that result from alternative approaches. Values are perceived as providing the basis of varied alternative ways to respond to a problem. Value considerations become a part of the decision-making process.

VI. *Education for the future.*

Historically, science teaching has looked backward to the accomplishments of the past rather than forward to the needs of the future. However, if educators adopt the framework proposed thus far by the preceding 'threads' of the science/technology/society 'fabric', a futures orientation seems most appropriate. The developing field of technology assessment is one attempt to look towards the future. Until fairly recently, it was assumed that all scientific and technological change must represent progress. However, with deterioriation of the physical environment, increasing population, and increasing energy problems, technology and its role in society have been increasingly questioned (Banta and Behney, 1980). Technology assessment is a comprehensive form of policy research that examines short-term and long-term social consequences of the application of technology. It has as its goal to provide decision makers with information about policy alternatives. The technology assessment process includes a wide range of methods, many of which involve making projections or forecasts about the future. Many of the techniques associated with technology assessment are similar to those used by educators in future studies (Haas, 1980).

By means of problem-centred courses, students can be given opportunities to anticipate future conditions and to become aware of the possible consequences of various alternative plans and actions.

WHAT IS MODERN TECHNOLOGY?

One of the major problems that science and social science educators have in developing and implementing science/technology/society education is coming to an understanding for themselves of modern technology. This is no easy task. In attempting to delineate a 'philosophy of technology', noted philosopher Hans Jonas distinguishes between two major themes:

'(1) the *formal dynamics* of technology as a continuing collective enterprise, which advances by its own "laws of motion", and,

(2) the *substantive content* of technology in terms of the things it puts into human use, the powers it confers, the novel objectives it opens up or dictates, and the altered manner of human action by which these objectives are realized'. (Jonas 1979)

The first theme considers modern technology as an abstract whole of movement, an enterprise and process. 'Every new step in whatever direction of whatever technological field tends *not* to approach an equilibrium or saturation point in the process of fitting means to end . . . but, on the contrary, to give rise, if successful, to further steps in all kinds of directions and with a fluidity of the ends themselves' (Jonas, 1979). Each technological innovation spreads quickly through the world community. The second theme considers technologies' concrete uses and their impact on our world and lives. It is easier to develop teachable materials about the second theme than about the first; however, in attempting to teach about the interaction of science, technology, and society in the modern world, the first theme is probably the more important.

Technology has been defined in many ways. One broad definition suggests that 'technology can be characterized as that form of cultural activity devoted to the production or transformation of material objects, or to the creation of procedural systems, in order to expand the realm of human possibility'. (Hannay and McGinn, 1980)

Other definitions of technology have been offered. Galbraith (1977) states that technology 'means the systematic application of knowledge to practical tasks'. Mesthene (1977) defines technology as 'tools in a general sense, including machines, but also including linguistic and intellectual tools and contemporary analytic and mathematical techniques . . . the organization of knowledge for practical purposes'. Given these definitions of modern technology, what are its characteristics?

Complexity. Technology encompasses both the simple and the complex. A windmill may be thought of as a technology. So may a multibillion dollar nuclear power plant. Many products of twentieth century technology are composed of hundreds, if not thousands, of parts. The parts are usually highly differentiated in nature and function. In order to work successfully, integration is required.

Remoteness. Modern technical devices extend human capabilities. The five senses, physical mobility, and human strength are all augmented by technological means. Transportation technologies increase one's ability to move in geographic space. Communication technologies expand one's power to see, hear, speak, and express oneself over great distances. A person's physical presence is not required for action to take place. 'Being there' can be substituted for by a number of sophisticated devices. However, a product of these extensions is a quality of remoteness, of '*not* being there'.

Obsolescence. For most of human history the norm has been tradition and continuity. Change was news. The most valued works were the oldest. Today, in contrast, scientists and technologists study preprints of articles and use the telephone to make sure that their work has not been made obsolete by what someone else did yesterday morning. New models of computers, word processors, equipment of all types rapidly make models a year old obsolete.

Rationality. Although the concept is difficult to deal with, scholars working with modern technology consider rationality as indispensable to any description of modern technological society. Rationality implies that something can be modelled in a formal design or programmed as a series of formal rules of operation, some systematic arrangement. The parts fit together correctly. Mass production of any product – automobiles, food, clothes – requires a rational plan in which steps in the process follow each other in a preconceived, appropriate sequence – a flow.

A Systems Context. Many products of modern technology are dependent for their manufacture, use, and maintenance on complex systems. Consider, for example, the automobile. What system do you buy into when purchasing an automobile? Does it not consist of a complex sociotechnical system that includes roads, fuel supply, maintenance facilities, insurance, registration, police control, and legal obligations? A web of interdependency exists among parts of the system.

Central Control. Coordination of a complex system may require central control. This means its working depends upon directions from a core. The Apollo space programs and the worldwide operations of organizations like ITT are examples of programs with centralized control.

A Global Character. The recent move toward modernization in China is an example of the trend toward global dissemination of advanced technologies of transportation, communication, and mass production. Reactions against sudden infusions of modern technology also are seen, as, for example, in some of the Arab nations.

Convergence. Convergence, the tendency for everything to become more like everything else, is a characteristic of modern technology. Nations are brought together and differences between the experiences of people are narrowed. Television, the great leveller, goes into the homes of rich and poor, young and old. Television broadcasting draws people into the same experience in ways never before possible.

Procedural Systems, or Social Technologies. In the past, technology was concerned primarily with production of material things – furniture, tools, machinery, jewelry. In recent decades, procedural and organizational systems have emerged as technologies. Such procedural systems provide specific plans for the production, management, and use of material artifacts. For example, computer software, in the form of computer languages and operating systems, is necessary before the hardware of the computer itself can be of any value. Organization and management theories and practices, along with teaching and training procedures, are other examples of social technologies.

Apraxia. Winner (1977) applies the medical term *apraxia* to technical systems. In medicine, the term is used to describe the inability to perform coordinated movements. In large-scale technology networks with complex interdependencies and interconnections, *apraxia* is a constant danger. Our technologically based society is one in which all systems must be go. When something gets out of kilter, as with blackouts due to power failure or severe oil shortages, the threat of technological *apraxia* becomes obvious.

THE SCIENCE/TECHNOLOGY/SOCIETY CURRICULUM MATERIALS GAP

Very few secondary school curriculum materials in the United States deal with issues of science/technology/society. There are a variety of reasons for this lag between perceived need and observed educational practice. The interdisciplinary nature of such materials is one such reason. While lip service is paid to the need for interdisciplinary curricular programs, departmentalized high schools do not lend themselves well to either the planning or implementing of such programs. Publishing firms are reluctant to try to market programs that do not have a readily identifiable target population, i.e., *either* the science *or* the social studies department.

Another reason for the dearth of materials is that science/technology/society issues by their very nature may be controversial. Many educators seek to avoid controversial issues in teaching-learning situations, particularly with the present political and educational climate. Science teachers, in particular, often do not feel competent to handle potentially controversial topics.

It is difficult to handle complex issues responsibly within the constrictions of the educational setting. The Panel on School Science of the National Research Council's Commission on Human Resources (1979) in discussing the goal of an informed citizenry notes the difficulty of providing students with enough relevant information to enable them as future citizens to deal intelligently with difficult political, economic, and social issues. In planning courses that seek to promote intelligent dealing with social issues that have a technological component

> 'delicate steering is necessary to avoid the levels of rigor and scientific sophistication that scare some students away and at the same time to avoid the mushiness of courses that are about but not of science, or that treat only the social aspects of a topic without giving students a better understanding of the underlying processes and principles'. (Panel on School Science, 1979)

'FIRST GENERATION' SCIENCE/TECHNOLOGY/SOCIETY CURRICULUM MATERIALS

In an attempt to begin to fill the gap existing for science/technology/society materials useful for general education at the secondary school level, the BSCS of Boulder, Colorado, with National Science Foundation support, developed and tested some pilot interdisciplinary STS curriculum materials during 1980-81. This program is called Innovations: The Social Consequences of Science and Technology (IST). The general purpose of the IST program was to develop interdisciplinary resource materials that could be used to educate the general citizenry in issues of science/technology/society that are important aspects of present and future social policy. The STS framework described earlier in this paper was the underlying context for the program. It was hoped that the IST materials and strategies would help students assess effects of selected technological innovations and consider the nature of the interrelationships between science, technology, and society. A further goal was to encourage students to become members of the 'attentive public' about science and technology matters.

The general learning objectives for the program as a whole were:

1. Students will report an increased awareness of the unprecedented dilemmas and ethical questions facing people as a result of science and technology.
2. Students will report an increased interest in and consumption of relevant public affairs topics related to science and technology.
3. Students will be able to identify and describe several scientific and technological developments that produce major effects in their own lives and the lives of others.
4. Students will develop an awareness that citzen participation in policy making is required if policies are to incorporate a common public interest and not be over influenced by various interest groups.
5. Students will be able to translate their clarified and informed values into participatory action in the classroom. This includes several of the following behaviours:
   a. identifying the components in a decision-making process;
   b. effectively presenting their views on issues;
   c. listening to people who hold different and opposing views;
   d. distinguishing between factual information and interpretation placed upon this information;
   e. utilizing the resources of experts without surrendering responsibility for choice to them.

The program consists of a general introductory module – *Science, Technology, and Society* – and eight other modules, each dealing with one or more technological innovations. Each module in the program attempts to answer, with varying degrees of emphasis, these five organizing questions:

- What is it? (How does it work?)
- How does it affect me?
- How does it affect us?
- How valuable to us it it?
- What might be its future?

Each resource module contains a variety of student materials, including various combinations of printed, taped, visual, and 'hands-on' components. Supporting teacher guides and evaluation materials were also developed.

The modules that were a part of the pilot IST program are

Science, Technology, and society
Day Care
Television
Low-head Hydropower
Computers and Privacy

Human Reproduction: Social and Technological Aspects
Energy: Technologies, Dilemmas, Options
Food Production
Biomedical Technology

Although planned as a semester program, the materials developed are sufficient to be used in many classroom settings for a year, depending upon their utilization.

Space will not permit detailed description of all of the modules of the program. Information about the program as a whole or selected modules within it can be obtained from BSCS.*

Science, Technology, and Society: An Introduction. The Science, Technology, and Society module was designed to introduce the general frame of reference for the program as a whole to the teacher, and as appropriate to the students, and to raise the awareness of students about the nature of science, technology, and society interrelationships. In using the module, students have opportunities to:

1. consider the nature of science, of technology, and of society, and to become aware of some possible interrelationships among these elements;
2. become aware of some recent concerns about science and technology and to differentiate among types of concerns;
3. be introduced to the decision-making model that is used throughout the program and use it for making a decision;
4. appreciate the role of values in personal and public decision-making;
5. become familiar with the developing field of technology assessment as a social technological innovation;
6. consider some possible relationships between technology and human control and utilization of it;
7. understand that control of technology is inseparable from control and organization of other aspects of social and economic activity and that there are a variety of alternative approaches to these issues.

The introductory IST module differs from the other modules in the program in a number of ways. The ideas presented are more abstract and difficult than those in the other modules that deal with more specific and concrete technologies and issues. Each of the six activities in the module is designed to be an all-class activity. The other modules contain some all-class activities that all students should do, some small group activities, and some activities that can be done by individual students. In the pilot test of the materials, teachers and students were offered choice in what was utilized. Not all students did all activities, nor did all teachers teach all modules. Because of a very short time-line for development of materials, the experimental version of the *Science, Technology, and Society* module contained much reading that was too difficult for high school students. The developers realized this at the time the material was put together; however, given the time and conditions under which the materials were developed, there was no alternative. Some test teachers presented the main ideas in some of the activities as lectures, or modified them in some other way.

---

* BSCS, 833 W. South Boulder Road; Louisville, Colorado, 80027, U.S.A.

Activity 1 introduced the general theme of the program, the interrelationships of science, technology, and society, through a diagram and six readings that related to the parts of the diagram. The areas of emphasis were 1) the nature of modern science; 2) some characteristics of modern technology; 3) some characteristics of modern society; 4) some relationships between science and technology; 5) some relationships between society and technology; 6) some relationships between science and society. A triangular science/technology/society diagram with arrows was used in various forms to symbolize each of the activities in the module.

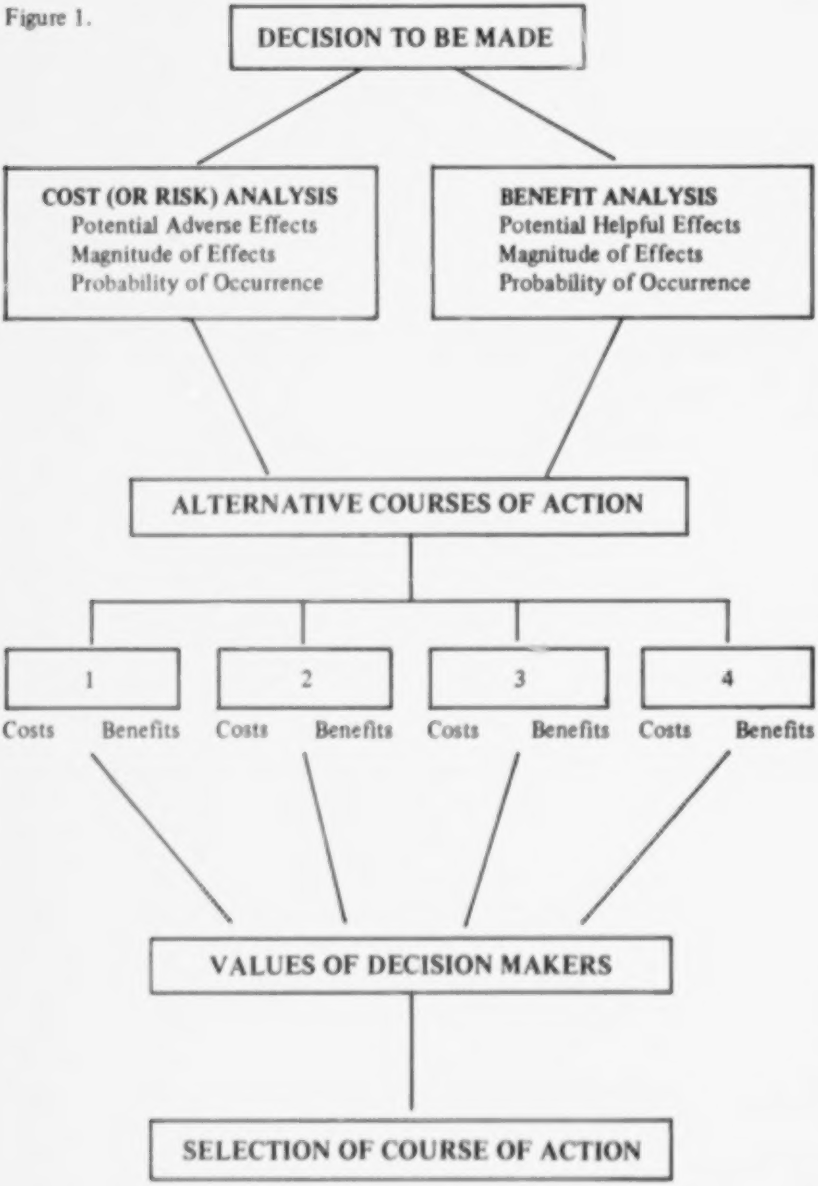
In Activity 2, a taxonomy identifying ten categories of concerns about technology and science was presented, based on the work of Loren Graham (1980). Graham's main objective in formulating a taxonomy of concerns about science and technology was to assess the validity of various concerns about science and technology, and to address issues of regulation and control as they related to each category of concern. As Graham states, there is a need

> '. . . to sort out those categories of concern about science and technology where we are coming to recognize the necessity or inevitability of controls of one sort or another while retaining other categories where freedom from control is defensible and necessary'. (Graham, 1980)

The decision-making model used throughout the program is introduced in Activity 3. (See Figure 1). The activity attempts to make explicit the various components of the model. Particular attention is paid to values as a 'critical filter' in the decision-making process. Students are asked to apply the decision-making model to a decision situation of interest to them at either the personal, community, or societal level. This particular model, unlike some other decision-making models, ends at 'selection of course of action'. In reality, of course, the action selected must be implemented, reflected upon, and evaluated as to its efficacy. Often the decision will need to be rethought and recycled throughout the decision-making process. The actual process is never as 'neat' as a model implies. The activity makes explicit one of the over-all program goals – to encourage students to become members of what political scientists have called the 'attentive public' about issues related to science, technology, and society (Miller, Suchner, and Moelker, 1980).

Technology assessment as a relatively new social technology for dealing with interrelationships of technology and society is explored in various ways in Activity 4. The five organizing questions for each 'innovation' addressed in the IST Program (What is it? etc.) are considered in regard to technology assessment. Students learn about the work of the Office of Technology Assessment (OTA) of the United States Congress in a number of ways: they read about its inception; participate in

Figure 1.


DECISION TO BE MADE
COST (OR RISK) ANALYSIS
Potential Adverse Effects
Magnitude of Effects
Probability of Occurrence
BENEFIT ANALYSIS
Potential Helpful Effects
Magnitude of Effects
Probability of Occurrence
ALTERNATIVE COURSES OF ACTION
1
Costs
Benefits
2
Costs
Benefits
3
Costs
Benefits
4
Costs
Benefits
VALUES OF DECISION MAKERS
SELECTION OF COURSE OF ACTION

a simulation of a hypothetical OTA panel assessing a new pharmaceutical product; and they study material from an actual OTA study. In the all-class simulation exercise in technology assessment – 'Deprezine' – students experience selected aspects of the technology assessment process through participation in a simulated OTA advisory panel convened to assess the potential impacts on society of the widespread introduction of a fictitious pharmaceutical, 'Deprezine', which eliminates physical dependency on alcohol. This simulation was designed by Clyde Behney, a project director in health programs of the Office of Technology Assessment. It replicates in a simplified way the manner in which an OTA panel operates. The exercise is part game, part simulation, and part scenario building, and has been well received by persons participating in it. In order to do the simulation the class is divided into eight small groups with each group playing the role of a member of an OTA 'Advisory panel on the social implications of "Deprezine".'

Following the simulation exercise and de-briefing, students utilize parts of an actual OTA study on coal slurry pipelines, a controversial form of transporting pulverized coal.

In Activity 5, students are introduced to the theme of 'autonomous technology' and given opportunity to speculate about the validity of that concept (Winner, 1977). Three ideas about human beings, technology, and control are presented. Students read short selections that agree and disagree with the three ideas presented. Students then participate in an exercise that raises questions from an open-ended inquiring perspective about the ideas presented. The second part of the activity uses Mary Wollstonecraft Shelley's early nineteenth century novel *Frankenstein* (not the movie version) as a parable about humanity's 'ambiguous relationship to technological creation and power' (Winner, 1977).

The concluding activity of the module considers three alternative approaches to the role of technology in society. The three approaches presented (Goldsmith and Allaby, 1972, Elliott and Elliott, 1976; Bookchin, 1972) are only three from a much larger group that could have been included. As with other activities in the module, an open-ended perspective is suggested. The main point of the activity is to convey the idea that issues related to technology and its use and management must be dealt with in a broad societal context. Depending on one's values, a variety of alternative approaches for dealing with the interrelationships of science, technology, and society have been and can be suggested.

The Biomedical Technology Module. The innovations or problems presented for analysis in the *Biomedical Technology* module illustrate the nature and scope of societal issues attendant to rapid progress in biomedicine. Four major themes are addressed:

1. The disparity between the rate of scientific and technological progress and the development of new legal, ethical, and moral guidelines to deal with the implications of that progress.

2. The plurality of values in society and the way that plurality affects application of scientific and technological advances.
3. The tenuous and incomplete nature of the data on which decisions are based; for example, decisions on new treatment or diagnostic procedures and the subsequent public policy decisions that result in the broad-based application of those procedures.
4. The role of the experts and the public in the development of public policy.

This module of the *Innovations: The Social Consequences of Science and Technology* program is designed to deal with the five general organizing questions as they apply to biomedical technology.

The chart in Figure 2 indicates the degree to which each activity addresses each question.

Other IST Modules. The *Day Care* module was developed to illustrate the concept of social technology; the idea that technology, defined as *a way of getting things done*, need not be a physical object. As physical technologies have evolved from simple, passive nonreactive tools like stones to the complex equipment of the industrialized world, so also have social technologies evolved. Patterns of human organisation in hunter-gatherer or agrarian societies seem simple when compared with the human roles found in a factory, a city, or a nation. *Day Care* explores the technologies that have been developed in response to the relatively new social phenomena of two career families and one parent families. The module asks three general questions:

- What are the characteristics of day care in this and in other communities?
- Why do adults seek day care for their children and what choices do they make?
- What are the effects of day care on children, families, and society?

Food Technology is a module primarily about decision making, but also about food. The subject of modern food science, technology, and decision making afford opportunities for consideration of government regulation. The module contains activities on nutrition labelling, standards of identity, consumer testing, advertising, environmental contaminants in food, today's food technologies, and promising technologies for tomorrow. The *Television* module investigates the impact of television on students' lives in the areas of perceptions of reality, consumerism, social roles, leisure time activity, and observation/participation in world events. Other topics dealt with include the influence of television on personal and social values and decision making, the relationship between television and children, and possible future uses of television.

In *Energy: Technologies, Dilemmas, Options* students carry out simple energy-related experiments and a variety of investigations related to present energy technologies, dilemmas, and options. Topics include nuclear energy, coal utilization, some aspects of solar energy, and home energy use. Conservation at the personal and societal level are topics of investigation. The module ***Low-Head Hydropower*** focuses more specifically on one energy source, low-head or small scaled hydroelectric power. Several proposed potential dam sites in Idaho are evaluated in terms of cost for construction, productivity, use of water, and environmental impact. A classroom simulation related to construction of a proposed power plant is a part of the module. Changing priorities involved in decision making about hydropower

Figure 2. Biomedical Technology Module.

Activity No.	Activity Title	What Is It?	How Does It Affect Me?	How Does It Affect Us?	How Valuable Is It?	What Might Be Its Future?
Intro	CHANGING PATTERNS OF SICKNESS AND DEATH	X	X	X		
1	PUBLIC UNDERSTANDING OF BIOMEDICAL SCIENCE The Importance of Data in Biomedicine and Health Care		X	XX	X	
	Sorting the Data	XX	X	X		
	The Role of the Media in Public Understanding of Science	X		XX		X
	Analyzing News Reports	X		X	XX	
2	GENETIC SCREENING Screening and Confidentiality	X	X	XX		
	Genetic Screening in the Workplace	X			XX	X
3	IN VITRO FERTILIZATION AND EMBRYO TRANSFER The Case For and the Case Against	X		X	XX	
	A Scenario for the Future			X		XX
4	PRENATAL DIAGNOSIS Why Is Amniocentesis Done?	X	X		XX	
	Amniocentesis and the Law			XX		X
	Amniocentesis and Public Policy		X	XX		X
	Is Amniocentesis Antinatalist or Pronatalist?			X	X	XX
5	RECOMBINANT DNA Patenting New Life Forms	X		X	XX	X
	Science as Business; the Scientist as Entrepreneur		X	X		XX
	What Would You Do?			X		XX

development are explored through use of the decision-making model employed throughout the program.

The major focus in the *Computers and Privacy* module is on present and future social consequences of the use of computers. The need for records of all types – insurance, medical, demographic, law enforcement, educational, consumer-related, employment – versus the need to protect people's privacy is the major theme of the materials. In *Human Reproduction: Social and Technological Aspects* a variety of topics related to the past, present, and future of human reproduction are considered. Technologies related to birth control, sex preselection, and clinical insemination are topics for study. Teenage pregnancy, adoption, and risks and benefits associated with birth control technologies are also included.

The IST program was pilot tested during 1980-81 by nineteen science and social science teachers primarily in public high school settings. Since each teacher did not use all nine of the modules, a full program level evaluation could not be carried out. All evaluation data has not yet been compiled; however, teacher feedback was generally positive, given the problems inherent in the experimental materials and identified by developers and teachers prior to their use. These difficulties include 1) reading materials that were very difficult both in terms of vocabulary, and conceptual complexity; 2) not enough variety in learning activities; insufficient use of media, laboratory experience, and simulations; 3) 'not enough science' from the viewpoint of some science teachers; 4) 'too much science' from the viewpoint of some social studies teachers.

An evaluation report from students and teachers in combined Humanities and Senior Science classes, team taught by Humanities and Science teachers, follows as an example of response to the program. The modules taught during the semester course included *Science, Technology, and Society; Television; Energy: Technologies, Dilemmas, Options; Computers and Privacy;* and *Biomedical Technology.*

1. 'Course content is valuable and considered a worthwhile addition to the high school curriculum. At present no other course presents the concepts as outlined in the Innovations program'.
2. 'There is a need to reduce the amount of writing and paper work required for each module. The large volume was somewhat necessary to provide feedback for evaluation purposes'.
3. 'Additional hands-on or laboratory experiences need to be incorporated into modules to greater facilitate a fuller understanding of the concepts presented. Such would also stimulate greater student interest. Students from the solid science backgrounds did not feel the program was as science oriented as it should have been. However, one need keep in mind that Innovations is not a course in Science'.
4. 'As the modules are written it is clear that only high ability students can cope with the concepts presented and the high reading level required to master the material . . .'

5. 'A wide range of background knowledge is somewhat necessary to fully appreciate and allow one to cope with the course content. Such supports offering the program only to upper secondary students with good reading ability to allow them to gain information through extensive reading of technical and semi-technical reports'.
6. 'The greatest problem facing adoption of such a program of study at M.C.H.S. is where to offer it within the existing curricular structure. To add a new course at the expense of our present hard science program would not be to the benefit of those students planning on science-related fields of study after high school. To offer the program within the Social Studies Department would not attract the science-oriented student for whom the program is intended. To have students without a strong science background take the course would probably find them frustrated due to the science concepts required for understanding the technologies that society is having problems with. To fully provide answers to problems one must appreciate the scientific means which have generated the present social issues'.
7. 'The teaching team with staff from both Social Science and Science disciplines made for an ideal approach to the subject matter, and was in direct accordance with the goals of the program. However, to make Innovations a part of the present Humanities/Senior Science either one semester or for one marking period would create problems.
   a) Humanities students from one year could be repeating as science students the following year.
   b) It would be necessary to revise the humanities curriculum; and objections were raised at the revisions that were necessary to allow for the pilot study.
   c) A revision of the senior science curriculum would also bring about a reduction in training along the lines of science'. (Winkler, Gahagan, Kennedy, Watson, 1981)

The evaluation report continued with some suggested solutions. 'To provide for the inclusion of Innovations into the curriculum the following suggestions have been offered.

1. Establish a new course to bridge the Science and Social Science curriculum. This program would have to take into account the various problems already indicated in this report, as well as the strengths indicated by the pilot program.
2. Revise present curricular programs to allow aspects of Innovations to be incorporated with minimal disturbance of present curriculum goals and practices.
3. Revise the Innovations program to provide more background for less

science directed students and expand laboratory experiences and then either fit the revised program into 1 or 2 above'.

Summary. 'Students with future roles as concerned and responsible citizens need to be prepared to deal with critical societal issues. They will require knowledge and attitudes that will lead to personal actions and public policies that will assist in resolving environmental problems; to reach those goals is the responsibility of both the science and social science curriculum'. (Winkler, Gahagan, Kennedy, Watson, 1981).

The BSCS staff had hoped to be able to follow up this pilot STS program with revision and improvement of materials and further field testing. A follow-up proposal was submitted to the National Science Foundation for substantive revision of the materials based on evaluation of the pilot materials. However, the National Science Foundation refused funding of the follow-up project.

The follow-up proposal was submitted at a time when both the Development in Science Education (DISE) and the Research in Science Education (RISE) programs of the Division of Science Education Development and Research of the National Science Foundation were in the process of being phased out of existence. Since that time, the National Science Foundation has virtually ceased funding of precollege science development and research. However, even if this were not the case, it is possible that a follow-up to the pilot IST Program would not have been funded. In their review of the follow-up proposal, NSF officials raised some question about the feasibility of meeting program objectives as initially stated. The conceptual complexity and sophistication of the experimental materials was questioned in terms of appropriateness for the target population. Suggestion was made that the developers seek funding from a publisher or foundation with interest in promoting education in the Humanities, since the materials were perceived by NSF reviewers as being more representative of a humanistic style of inquiry than a scientific one (Hannapel, 1981).

AN EDUCATIONAL DILEMMA FOR THE 1980s

The recent experience of the BSCS in attempting to develop pilot 'first generation' science/technology/society materials conceived within the framework for science/technology/society education increasingly advocated by science educators raises several important points for consideration. Substantive questions about the feasibility of such education remain unanswered at this point in history. More importantly, substantive questions may not yet even be being asked. What are some of these areas of concern?

1. The cognitive complexity of issues under consideration as part of education about science/technology/society is formidable. Yet, the recommendation is made that such issues should be a part of ***general education*** for citizens in a democracy. Research over the past decade (for example,

McKinnon and Renner, 1971) has indicated that many college students and adults in the United States are concrete thinkers (in Piagetian terms) – persons who are not able generally to deal with abstractions. Yet interrelationships of science and technology with society involve abstractions. Are there ways in which to formulate such types of issues and problems so that they are understandable and able to be investigated by large segments of the population as a part of general secondary education? How much background knowledge must students possess before they can bring meaning to issues included in such a program? Such questions need to be extensively researched.

2. By its very definition, science/technology/society education must be interdisciplinary in nature. Yet educational institutions at all levels, publishers, and even private and public foundations have great difficulty in even beginning to operate outside of discipline-bound frames of reference. National Science Foundation staff questioned further funding of an STS program because it was perceived as having some 'humanities orientation'. At the same time, they have commissioned studies that consistently recommend interdisciplinary education in order to bring about understanding of science *in* society. Other experts also suggest that 'the humanities, sciences, and technology need to be substantially connected "cultivating" a literacy that enables everyone to view technology rationally and to understand the broad dimensions of scientific inquiry' (Commission on the Humanities, 1980).
3. The question of how much understanding *of* science is necessary for persons to understand anything *about* science in a legitimate way needs answering. The issue needs research not rhetoric. Yet, there is little evidence that such research will be initiated, supported or completed in the next years.
4. A similar question can be raised about technology. How much understanding *of* technology is necessary before one can understand *about* technology and its role in the present day world? What *is* the domain of technology education? What types of educational experiences involving technology are appropriate for particular target populations? Since secondary school curriculum development involves translation of scholarly material into forms and experiences appropriate for general education, curriculum developers must understand the scholarly base upon which they draw. At present, within the community of scholars many interpretations of technology and its effects can be found. Only an 'incipient' philosophy of technology exists that asks the basic questions necessary to understand technology as both formal dynamics and substantive content (Jonas, 1979). This state of the art thus poses an intellectual challenge to would-be curriculum developers.

5. A similar question can be raised about the 'society' component of science/technology/society education. How much understanding *of* society is necessary before one can understand anything *about* it? How much sociological, political, historical, and economic knowledge is necessary before persons can comprehend the substance of issues raised in education about science, technology and society? Again, research is required in order to answer such questions.

Science educators and scientists have long been concerned with improvement of 'scientific literacy'. Yet, definition of what is meant by 'scientific literacy' is no easy task. Branscomb (1981) recently suggested eight different types of scientific literacy that should be considered depending upon the purpose one was concerned with. Many differing meanings are also implicit in the term 'technological literacy'. What definition is most appropriate as part of general education for citizenship within a democracy? Once defined, how can such literacy be best built into the school curriculum?

Some persons are beginning to question the validity of the premise that democratic public policy consideration dictates that the general public be informed about science and technology (Trachtman, 1981). An assumption behind the science/technology/society educational framework in this paper is that

> 'the very structure of a democratic society depends upon the existence of an enlightened citizenry. The political and social behaviour of this citizenry in voting, in influencing elective and appointive officials, and in engaging in political and social activisim, will be more constructive for society if it is informed by solid scientific understanding'. (Trachtman, 1981)

Yet, Trachtman points out that in many areas of science/technology/society interaction 'the more profound the understanding of the scientific and technical evidence, the greater the probability of ambivalence and political paralysis'. (Trachtman, 1981)

Thus, it seems that at this point in history three basic questions need to be asked and answered before much definitive work can be done in developing and implementing science/technology/society curriculum materials as part of general education for participation in a democracy. These questions are:

1) *Can we?* That is, can we really *do* such a type of education, even if we want to? Is science/technology/education as a part of general education even a viable possibility?
2) *Should we?* That is, if we find through research that such education is possible, what effects does it have on the persons who receive it? Are they more or less effective citizens? More or less effective decision makers? Do they become more active citizens as a result of such education or do they become 'paralyzed' with too much knowledge about issues under consideration? Does such education make any difference in peoples' attitudes and behaviour?

3) *How do we?* If we determine that we can, and that we should, then *how* do we best bring about interdisciplinary curriculum development, testing, revision, and dissemination in a time when very few individuals and institutions seem interested in such an effort?

In the present educational and political climate of the United States, it seems unlikely that these questions will receive much attention or research support. Until such research efforts are made, however, it appears unlikely that we will have the necessary data upon which to base decisions necessary to the implementation of a science/technology/society framework for education.

REFERENCES

AARONIAN, R. S., BRINCKEROFF, R. F., COMPTON, C.A. and POLYCHRONIS, A.A. *The Exeter conference on secondary school science.* Exeter, New Hampshire: Exeter Academy. 1980.

ADVISORY COMMITTEE FOR SCIENCE EDUCATION *Science education – the task ahead for the National Science Foundation.* Washington, D.C.: National Science Foundation. 1971.

ADVISORY COMMITTEE FOR SCIENCE EDUCATION. *Science education for the 1980's.* Washington. D.C. The National Science Foundation 1980.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. *EVIST resource directory.* Washington, D.C.: American Association for the Advancement of Science. 1978.

BSCS. *Innovations: the social consequences of science and technology program. Experimental Edition.* Boulder, CO: BSCS (Biological Sciences Curriculum Study).
Biomedical Technology. 1980.
Computers and Privacy. 1980.
Day Care. 1980.
Energy: Technologies, Dilemmas, Options. 1980.
Food Technology. 1980.
Human Reproduction: Social and Technological Aspects
Low Head Hydropower 1980.
Science, Technology, and Society 1980.
Television 1980.

BANTA, H. D. AND BEHNEY, C. J. 'Policy formulation and technology assessment', *Milbank Memorial Fund Quarterly: Health and society.* 1980.

BARR, R. D., BARTH, J. L. AND SHERMIS, S. S. *Defining the social studies.* Arlington, VA.: National Council for the Social Studies, Bulletin 51. 1977.

BENNE, K. D. AND BIRNBAUM, M. 'Teaching and learning about science and social policy'. Background paper for the 1978 Social Science Education Consortium Conference, Boulder, Colorado. 1978.

BOOKCHIN, M. 'Towards a liberatory technology' in G. Benello and D. Roussopoulos (eds.) *The case for participatory democracy.* Grossman Publishers. 1971.

BOTKIN, J. W., ELMANDJRA, M. AND MALITZA, M. *No limits to Learning: Bridging the Human Gap.* A report to the Club of Rome. Pergamon Press: Oxford. 1979.

BRANSCOMB, A. 'Knowing how to know'. *Science, Technology, and Human Values.* Vol. 6:36. Summer 1981.

CHARLES, C. AND SAMPLES, B. (EDS). *Science and society: Knowing, teaching, learning.* Arlington, VA: National Council for the Social Studies, Bulletin 57. 1978.

COMMISSION ON THE HUMANITIES. *The humanities in American life.* Berkeley, CA: University of California Press. 1980.

DIVISION OF HEALTH, SCIENCE and TECHNOLOGY, BUREAU OF CURRICULUM SERVICES, PENNSYLVANIA DEPARTMENT OF EDUCATION. *Technology: meeting the technology portion of the science and technology goal of quality education*. Undated..

ELLIOTT, D., and ELLIOTT, R. *The Control of technology*. London: Wykenham Publications. 1976

GALBRAITH, J. *The new industrial state*. New York: New American Library. 1977.

GOLDSMITH, E. and ALLABY M. *A blueprint for survival*. London: Penguin. 1972.

GRAHAM, L. R. 'Concerns about science and attempts to regulate inquiry'. *Daedalus* Vol. 107:2, 1978. Journal of the American Academy of Arts and Sciences.

HAAS, J. *Future studies in the K-12 curriculum*. Boulder, CO. ERIC Clearinghouse for Social Studies/Social Science Education and the Social Science Education Consortium. 1980.

HANNAPEL, R. Personal Letter to Dr. Richard Tolman, BSCS, Boulder, Colorado. February 18, 1981.

HANNAY, N. B. and MCGINN, R. E. 'The anatomy of modern technology: Prolegomenon to an improved public policy for the social management of technology'. *Daedalus* 109:1 Winter, 1980.

HARMS, N. S. AND YAGER, R. C. *What research says to the science teacher*. Washington, D.C.: National Science Teachers Association. 1981.

HELGESON, S., BLOSSER, P. and HOWE, R. *The status of precollege science, mathematics, and social science: 1955-1975. Volume I: Science education*. Columbus: The Ohio State University Centre for Science and Mathematics Education. 1977.

HUFSTEDLER, S. M. and LANGENBERG, D. N. *Science and engineering education for the 1980's and beyond*. Washington, D.C.: National Science Foundation and the Department of Education. 1980.

JONAS, H. 'Toward a philosophy of technology'. *Hastings Centre Report* Vol. 9:1 (February 1979).

LAKOFF, S.A. 'Scientists, technologists and political power'. In Spiegel-Rösing, I. and Price, D. deS. (Eds.) *Science, technology and society: a cross-disciplinary perspective*. Beverly Hills: Sage Publishing, Inc. 1977.

MCKINNON, J. W. and RENNER, J. W. 'Are colleges concerned with intellectual development?' *American Journal of Physics* 39. 1971.

MESTHENE, E. 'The role of technology in society.' In A. Teich (ed.). *Technology and man's future*. New York: St. Martin's Press. 1977.

MILLER, J. D., SUCHNER, R. W. and MOELKER, A. M. *Citzienship in an age of science*. New York: Pergamon Press. 1980.

MORRISSETT, E. (ED.) *Concepts and structure in the new social science curricula*. New York: Holt, Rinehart and Winston, Inc., 1967.

NATIONAL ASSESSMENT OF EDUCATION PROGRESS *Science achievement in the schools: A summary of results from the 1976-77 National Assessment of Science*. (Science Report No. 08-S-01.) Denver, CO : Educational Commission of the States, 1978.

NATIONAL COUNCIL FOR THE SOCIAL STUDIES. *Science and technology for a global society*. Vol. 43:5 (October 1979) Washington, D.C.: National Council for the Social Studies.

NATIONAL RESEARCH COUNCIL. *Seminars on educational policies in science and engineering*. Washington, D.C.: The National Academy of Science. 1980.

NATIONAL SCIENCE FOUNDATION. *What are the needs in pre-college science mathematics, and social science education? Views from the field*. SE 80-9. Office of Program Integration, Washington, D.C.: Government Printing Office, 1980.

NATIONAL SCIENCE TEACHERS ASSOCIATION. *Science education: accomplishments and needs*. Washington, D.C.: National Science Teachers Association, 1978.

PANEL ON SCHOOL SCIENCE, 'The state of school science' on behalf of the National Academy of Sciences, National Research Council, in *What are the needs in precollege science, mathematics, and social science education?* Washington, D.C.: National Science Foundation. 1979.

PIEL, E.J. 'Teaching science, technology and society issues in secondary schools.' A Report of the Science/Technology/Society focus group of Project Synthesis at the American Association for the Advancement of Society Meeting, January, 1980, San Francisco, CA.

PROCEEDINGS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES. *Science and public: the changing relationship. Daedalus* 103:3, 1974.

PROCEEDINGS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES. *Limits to scientific inquiry. Daedalus* 107:2, 1978.

PROCEEDINGS OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES: *Modern technology: problem or opportunity. Daedalus* 109:1, 1980.

SHANE, H. G. 'The Silicon Age and education'. *Phi Delta Kappan.* Vol 63:5 (January 1982).

SPIEGEL-RÖSING, I. and PRICE, D. deS (Eds.) *Science, technology and society: a cross-disciplinary perspective.* Beverly Hills: Sage Publishing, Inc. 1977.

TRACHTMAN, L. E. 'The public understanding of science effort: A critique.' *Science, Technology, and Human Values* Vol 6:36, Summer 1981.

WEISS, IRIS R. *Report of the 1977 national survey of science, mathematics, and social studies education.* Research Triangle Park, North Carolina; Center for Educational Research and evaluation. 1978.

WINKLER, R., GAHAGAN, C. KENNEDY, M., and WATSON, R. 'An evaluation of the pilot program Innovations: the social consequences of science and technology'. Presented to the Curriculum Council. April 9, 1981. Mimeo.

WINNER, L. *Autonomous technology: Technics-out-of-control as a theme in political thought.* Cambridge, Massachusetts: Massachusetts Institute of Technology Press. 1977.

Studies in Science Education 9 (1982), 33-46

Science Education for Citizens: Perspectives and Issues

I. Science, Technology and Society: Issues for Science Teachers

P. JAMES GASKELL
Department of Science Education, University of British Columbia

Introducing a focus on the interaction of science, technology and society (STS) into school science curricula was one of the major themes of the 1979 International Symposium on *World Trends in Science Education* (McFadden, 1980). The inclusion of an STS focus has also been a central recommendation of recent major policy documents on science education in the United States and England (Association for Science Education, 1979 and 1981: Harms and Yager, 1981: Hufstedler and Langenberg, 1980). In Canada the first three discussion papers (Aikenhead, 1980: George, 1981: Page, 1979) produced by The Science Council of Canada study of Canadian science education have argued for a greater emphasis in science teaching on the applied aspects of science and the ways in which science and technology interact with society, particularly Canadian society. The major recommendation of the 1978 British Columbia Science Assessment report (Hobbs, 1978) was that a thorough revision of the junior secondary science program be carried out. This revision 'should be designed to foster the development of skills in designing and interpreting experiments, and *to help students relate science to current issues and practical applications*' (p.44, emphasis added). This paper will discuss the interests of various social groups in supporting this broad trend, point to some of the issues in STS curricula that need to be addressed by science teachers and describe some of the organizational decisions that need to be made in developing curriculum materials with an STS focus.

THE SOCIAL CONTEXT

Widespread support by science educators for the inclusion of an STS emphasis in science teaching can be seen as a response to the perceived state of crisis in science education (Yager, 1980 and 1981). The crisis results from cutbacks in support for curriculum projects, research, and staffs of science education centres. In contrast to the 60's where prominence was given to science courses, today the back to the basics movement generally excludes science as a basic (Andrew, 1980).

The setbacks for science education stem, in part, from declining public interest in current school science programs though not necessarily in science itself. As Herbert Thier expressed it: 'Society is extremely concerned about science. Society is extremely involved with science. The only problem is it doesn't happen to be the science we practise as a profession'. (Yager, 1980).

The move away from the 60's courses that emphasized science as a discipline recognizes that the large majority of students do not need pre-professional training in science. A shift towards a science curriculum that is more personally and socially relevant, it is argued, would be more appropriate for students who will be future consumers of science rather than future producers (Aikenhead, 1980). Such a shift in focus might also help to increase the participation rate of women in upper level, elective science courses (Kelly, 1981).

Science educators are not alone in supporting a fundamental re-examination of the goals for science education. Governments, unions, consumer action groups, environmentalists, industrialists and scientists in various ways are supporting the broad concept of increasing the public's awareness of the interaction of science, technology and society.

Widespread support ought to make it easier to get money to develop curriculum materials and to effect change in schools. Widespread support for the broad concept, however, does not necessarily entail agreement over the specifics of implementation. Agreement, in fact, is hard to find. *Project Technology* illustrates the difficulties that can be encountered. Various interest groups supported the idea of the project but for conflicting reasons.

> Industry wanted it to persuade more able young people to wish to go into industry; professional engineers wanted it to persuade more bright people to become engineers; conservationists wanted it to teach children what wicked effects technology was having and how technology must be stopped at all costs; some teachers of science saw it as being their preserve, other teachers of science said it was nothing to do with them (Harrison, 1980).

In Canada it is difficult to construct an energy curriculum that satisfies both utilities and their critics (Beattie, 1980).

Conflicts over STS curricula reflect controversy over the technologies and scientific issues they explore. Usually conflict over the impact of science and technology on society reflects the varying interests of the different groups involved. This is as true historically as it is today. The story of sawdust pollution in late nineteenth century Canada is a good example (Gillis, 1980). The pollution resulted from lumber mills dumping all their waste into the rivers. The sawdust and bark slabs were a navigation hazard, fouled fish spawning beds and polluted the drinking water. People dependent on the river for transportation, fish and water lobbied for controls. Laws were passed limiting the company's rights to dump their wastes into the river. The owners of the lumber mills threatened to close down their plants and throw their workers out of work rather than pay the cost of anti-pollution measures. Regulatory agencies were established to monitor compliance. The industry, however, used its economic power to put pressure on the agencies not to enforce the laws strictly and to find solutions acceptable to industry. Industry hired Sir Sandford Fleming, a prominent scientist, to investigate and report on the conditions of the Ottawa River. He found no great difficulties ensuing from sawdust dumping except a navigation problem at the mouth of the Rideau Canal. Fleming's report was contradicted by scientists hired by the Department of Marine and Fisheries. Only after continued strong political pressure, buttressed by overwhelming documentation of the harmful effects of sawdust on the river system, was strict compliance to regulations enforced. At this point, the lumber companies began to experiment with new technologies to mill waste to produce pulp, fibre-board and acetylene.

Today there is an increased sense of urgency about the effect on our lives of the interaction between science, technology and society. This urgency comes from the increased rate of production of new products and the concomitant decrease in time to adjust to each new change. For example, the last forty years have seen the development of television, computers, jet planes, satellites, plastics, nuclear power, transistors, Xerox, oral contraceptives, LSD, PCB, DDT and DES. Not only is the rate of change increasing but the impact of the changes is more far reaching – particularly their potential for harm (nuclear explosions, depletion of the ozone layer, virulent new diseases from recombinant DNA research), their potential for affecting the organization of work (the installation of new technologies in business offices and newspapers) and their potential for challenges to deeply held ethical positions (contraception, abortion, human cloning).

There has been a tendency for people to believe that every problem, personal and social as well as natural and technical, could be solved by an appropriate science. However, scepticism about the advice of experts is increasing as consumers are repeatedly faced with conflicting recommendations from opposing experts. In recent years, people have been bombarded with conflicting advice over the advisability of eating fats, sweetening their coffee with saccharin, spraying with propellants containing freons, fluoridating water or sending their children to schools in which asbestos fibres contaminate the air. The tragedies resulting from the use of Thalidomide and the near tragedy of Three Mile Island have heightened sensitivity to the negative effects of science and technology on society. Large scale projects such as hydroelectric dams, nuclear power plants and pipelines in environmentally sensitive areas are particularly subject to widescale public debate. The traditional authority of governments to make decisions about such projects on their own has been challenged. In response, governments have developed a variety of mechanisms such as public enquiries, science courts and information dissemination to increase public participation in decision making. However, an analysis of several such efforts suggests that their main purpose is to increase the acceptance of controversial technologies and to restore the legitimacy of decision making institutions (Nelkin and Pollack, 1979).

These attempts to allay controversy are not always successful. Sometimes the procedures are challenged for not allowing sufficient opportunity for the presentation of opposing points of view. Thus, the Committee on Nuclear Issues in the Community, which was set up by the Canadian Government to promote broader public understanding of nuclear-related issues, was challenged by the Canadian Coalition for Nuclear Responsibility and Energy Probe for not presenting both sides of the 'debate' fairly (*Technology on Trial*, 1979).

The British Columbia Royal Commission of Inquiry on Health and Environmental Protection – Uranium Mining (RCIUM) heard representation from a wide variety of groups including industry, unions, doctors, environmental groups, church groups and community groups. However, rather than resolve controversy, it seemed to create it. The inquiry was closed prematurely by the government and a seven year moratorium on uranium mining was imposed.

The inquiry was interesting for the picture of science that it presented. The inquiry's mandate was to recommend to the government guidelines for the protection of the health and safety of people working in, or living around, uranium mines. On the surface this was a simple enough task: ask knowledgeable scientists what radiation levels produce what incidence of disease; ask engineers what technologies are currently available for controlling radiation levels, and then establish an industrial standard that balances the risk of disease with the economic and technical feasibility of controlling the level of radiation. In other words, ask experts for technical information, and then combine this with moral and political judgements about acceptable risks. The assumption behind such a description of the task is that technical information is neutral. The uses to which it is put are not. But scientific experts disagreed on their facts about the relation between radiation levels and disease and about what kind of radiation it was important to monitor. The scientific differences tended to reflect different value priorities: the economic health of the mining industry versus the physical health of the mine workers and nearby communities. The relationship between value priorities and technical information brought into question the neutrality of technical expertise.

Behind the controversy surrounding these government sponsored forums are two points of view. One is that the reason particular groups are opposed to a specific technological project is because they are uninformed or misinformed. If the public only had the information that the Canadian Atomic Energy Commission had, their apprehensions would dissolve. Science is seen to have objective and noncontroversial knowledge. The second viewpoint is that differences are real and cannot be changed by more information because the information itself is part of a political point of view. This argument rests on the assumption that the production and presentation of scientific information inevitably involves political and moral judgements about what questions are important to ask, what information is important to include in a presentation and what constitutes an acceptable interpretation of the evidence.

Increasingly social and political groups are taking the second position and not relying on someone else's expert scientists. For example, unions are challenging the exclusive right of management to collect data on occupational health and safety issues. Thus, workers in the Kitimat aluminum smelters who were concerned about the incidence of industrial disease, hired a team of scientists to collect and interpret data rather than rely on data collected by company doctors. Behind this move is an assumption that medical scientists hired by management will ask different questions and offer different interpretations than those hired by unions.

Different groups have different views about science and about the nature of its interaction with society. In responding to various pressures to incorporate a science, technology and society focus into teaching, science teachers must be aware of the nature of these differences and their implications for curriculum development.

ISSUES IN SCIENCE, TECHNOLOGY AND SOCIETY CURRICULA

Calls for changes in a curriculum to incorporate a science, technology and society focus tend to fall into three broad areas. These are: 1) a greater emphasis on technology; 2) a greater emphasis on the philosophical and cultural nature of science; and 3) a greater emphasis on science and social issues.

Technology

There are two general approaches to the teaching of technology in the schools: one emphasizes technological design and the other technological appreciation. Technological design involves students creating solutions to social needs through the design of new products. The design process involves the application of scientific and technological principles taking into account economic, political and aesthetic constraints.

Project Technology funded by the (British) Schools Council is a good example of a curriculum project emphasizing the design aspect of technology (Harrison, 1980: Marshall, 1974). Its broad aims were to make children aware of the technological forces affecting them and available to them and to make them aware of their ability and responsibility to control these forces. The project felt the best way to achieve this aim was to involve children in the process of technological design. This process would extend the student's technological resources in terms of theoretical knowledge and practical skills. It was argued that the ability to apply a scientific principle in the solution of a problem was the real test of understanding. Projects ranged from a device attached to the flushing mechanism of a toilet that acted as an alarm in case an elderly person living alone collapsed and was unable to call for help, to a sophisticated, electronically controlled, highly manoeuverable motorized wheelchair.

An emphasis on design may increase students' confidence in their ability to manipulate materials, apply scientific principles and understand some of the constraints on the design of technical solutions. It is less likely to engage students directly in examining the effect of current technology on their lives or of alternatives to 'technological fixes'.

Technological appreciation emphasizes existing uses of science and technology in everyday life and in industry. It stresses an appreciation of the significance, power and limitation of science in its wider social and moral context (Woolnough, 1975). David Suzuki argues that our present science education has neglected this dimension through its concentration on scientific facts and theories (Suzuki, 1980). As a consequence, when he (as a broadcaster) asks people whether science affects them in their daily lives the majority of people answer 'No, not really'. Unless people recognize the enormous impact that developments such as micro chips and genetic engineering can have as positive or negative forces in their lives, they cannot begin to exert any control over the development of these forces.

Scientists and engineers, faced with declining financial support for their research, are likely to argue that students and the public do not appreciate the benefits of science and technology enough. For example, a Science Council of Canada discussion paper written from an engineer's point of view argued,

> While science education has become more specialized and the proportion of students studying science has dropped, the benefits of science and technology have become less and less self-evident and public support for science has declined. . . To the dismay of many scientists, the support for scientific research that still exists is based solely on potential economic returns (George, 1981).

In the United States the National Science Foundation and Department of Education report to the President made a similar point (Hufstedler and Langenberg, 1980). The report argues that the contribution of science and technology to the security and prosperity of the nation rests upon two bases. One is an increase in the pool of competent scientists and engineers needed to maintain industrial competitiveness vis-à-vis other countries. The other is a public that understands it reaps the benefits of science and technology and is involved in influencing governmental and industrial source of funding for scientific and technological endeavours.

Implications for curriculum are not set out explicitly but the Canadian paper implicitly endorses a return to older styles of science textbooks. In contrast to the abstract, mathematical orientation of the new books, the older books established the industrial, social and economic basis of a topic before introducing theoretical scientific principles. Principles were followed by examples of specific application so that the student could understand the use of science in the practical world.

Groups that are interested in shifting technological development priorities from military hardware to mass transit or from nuclear energy technology to solar technology are not likely to be satisfied with a curriculum that stresses the benefits of current technological achievements.

Philosophical and Cultural Nature of Science

Another way of teaching about the interaction of science, technology and society is to stress the characteristics of scientific knowledge as distinct from other forms of knowledge such as economics, aesthetics or religion. Understanding the nature of theoretical scientific knowledge, its possibilities and limitations, is necessary before combining it with other knowledge to make practical decisions about how to act.

Separation of Substances (Roberts, McLeod and Orpwood, 1981) and *Science: A Way of Knowing* (Aikenhead and Fleming, 1975) are two Canadian curricula that take this approach. *Separation of Substances* is built around a simulation in which students develop technical advice about water supply treatment for a fictitious island community. Common separation techniques such as sedimentation, scum removal, filtration, flocculation and distillation are investigated for their technical advantages and limitations. Central to the unit is the distinction between technical and practical advice. Technical advice is a value free collection of knowledge statements about the probable consequences of particular actions. Practical advice is advice about what a person or a decision making body should do. Practical advice is based on an examination of different kinds of knowledge such as technical, economic and political, and on a set of value assumptions.

The trouble with this distinction is that for many of the controversial issues of today such as uranium mining, nuclear energy and the carcinogenic effect of certain chemicals, there is conflicting technical advice. As was seen in the case of uranium mining, the technical advice tends to reflect the value assumptions of the principal investigator. For a long time sociologists of knowledge excluded science from their investigations of how specialized bodies of knowledge were influenced by the social and cultural contexts in which they were produced (Mulkay, 1979). Science was seen as being independent of cultural context. This view of science has been strongly challenged by recent work in the area which seeks to show that not only the direction of scientific development, but also the ideas and content of science are responsive to social forces (Knorr, Krohn, Whitley, 1981: Latour and Woolgar, 1979: Mulkay, 1979: Ravetz, 1971). The intellectual foundations for sexism, racism and the present class structure have been supported by sciences which have developed ways of viewing the world consistent with prevailing values (Ann Arbor Science for the People Collective, 1977: Gould, 1981: Rose and Rose, 1976).

Conflict over a curriculum such as *Separation of Substances* is likely to arise between scientists, who see it in their interests to foster an image of science as being value free, and political groups interested in challenging that image.

Science: A Way of Knowing (Aikenhead, 1979: Aikenhead and Fleming, 1975), a grade ten course developed in Saskatchewan, touches upon cultural influences on science. The course is divided into three sections. In the first section, students investigate some of the different ways their community gains and uses knowledge, such as through economics, religion, art, and politics. In the second section, science is studied in more depth as one of the ways humans create and use knowledge. In the last section, students study the ways in which the community is affected by science and the ways in which science is affected by the community. In this last section, for example, the idea that military people, economists and unionists would give different priorities to proposed research projects is presented. In addition, questions are asked about the possible interaction between scientific ideas and the way people view the social order.

The idea that science should be presented as part of Canadian culture and used to foster the creation of a Canadian identity has been forcefully argued in a discussion paper distributed by the Science Council of Canada (Page, 1979). It argues that Canadians are ignorant of Canadian accomplishments in science and technology, of the way science and technology shape Canadian society and of the need to focus Canadian research on specifically Canadian problems. Efforts must be made to overcome a general tendency to disbelieve there is such a thing as a history of Canadian science and technology and that if Canadians have ever achieved anything in these fields it must be a pale imitation of more creative work done elsewhere (Sinclair, 1980).

One interpretation of this call for greater Canadian content is *Canadians' Contribution to Science* (Greaves and Williams). This set of materials gives thumbnail biographical sketches of forty-five Canadian scientists and brief descriptions of a few Canadian inventions such as insulin and the tuck-away beer carton handle. While these materials can foster a sense of pride in past accomplishments they avoid larger issues of whether scientists should respond to Canadian political priorities or whether scientists should ignore national boundaries and choose problems according to individual interest. It is to be expected that the scientific community will argue most strongly for the individual autonomy of scientists.

A focus on the philosophical and cultural nature of science, even if it avoids controversial issues of the day, is likely to create conflict between groups who view science as international, value free and responsive only to internal forces and groups who view science as culture dependent, value laden and responsive to external forces.

Science and Social Issues

The most common approach to science, technology and society curricula is to focus on social issues that have a significant science and technology component. Energy, food shortages, and pollution are common examples of such issues. These curricula are concerned with developing in students an awareness of the role science and technology play in creating and solving social problems, and with developing a sense of responsibility to influence the resolution of these problems. Given the nature of the issues, a science and social issues curriculum must involve teachers and students in areas of political and ethical controversy.

While science curricula have not been entirely devoid of controversy in the past, science teachers have worked hard to avoid it. For example, human reproduction has been ignored in favour of frog reproduction. A similar tactic is sometimes tried in STS curricula. For instance, the energy curriculum materials sponsored by British Columbia Hydro (Spratt), and supplied free to every B.C. school, excluded any discussion of nuclear energy, ostensibly because it is not needed at present in B.C. However, the same justification could also be used for other energy sources such as wind which are discussed in the curriculum.

The political forces which have a stake in bringing science related issues to the public's attention will also have a stake in seeing their points of view fairly represented in STS curricula. In an analysis of several Canadian and English energy units, however, it was found that the issues were presented in such a way that the economic interests of the energy industry were not seriously challenged (Gaskell, 1981). In dealing with the question of what energy technologies would be appropriate for the future, the soft energy path developed by Lovins (1977) is not discussed. No mention is made of important concepts such as matching scale to end use, or matching energy quality to end use. Although the curricula do discuss renewable energy technologies such as solar, wind, biomass, etc., they are not discussed as technologies which can be considered in the near future. Lovins, in contrast, argues that the transition away from an oil economy can be made both more cheaply and more quickly by relying on soft rather than hard technologies. Whether Lovins is right or wrong is immaterial: a legitimate and important alternative that would challenge the interests of the energy corporations is neglected.

In looking at the relationship between science, technology and industry, it is important to be sensitive to the various interests involved. Industry will emphasize the role of science and technology in inventing new products, solving production problems, increasing productivity and thus generating wealth needed to pay for social programs. Unions are likely to have a different set of concerns. One Canadian curriculum where the effect of new technologies on the lives of workers is explored in some detail is *The Technology Connection: The Impact of Technology on Canada* (Botting, Gerrard and Osborne, 1980). This curriculum explores questions about the way in which machines influence the quality of work life in positive and negative ways, questions about occupational health and safety, questions about who controls the development of machines and questions about who benefits in what ways from the introduction of new machines. This curriculum was prepared by social studies teachers and although it deals with basic issues about the impact of technology on society it does not deal with the scientific and technological principles behind the machines.

A discussion of industrial uses of science introduces a larger issue. To what extent will alternative ways of organizing the production of distribution of goods be presented? The English *Science and Society* course (Lewis, 1981), for instance, has been criticized on the grounds that it fails to present in a balanced way alternative political conceptions of the relationship between science, technology and society. 'In the major section on industry in the economy the capitalist system is implicitly accepted and the virtues of competition underlined. It does not seem to have been recognized that an alternative, socialist viewpoint exists' (Preece, 1981).

One of the justifications for discussing social issues is that it will help people to understand and make better decisions about important issues of the day. Should teachers and curricula encourage and assist students to act on the knowledge they gain or should education in schools be limited to imparting knowledge? It could be argued that having students attempt to influence a decision in a public forum would be an excellent motivating device for students to learn about the complexities of an issue. It would also force a discussion of a crucial but neglected issue in STS curricula – how can decisions be influenced? Is voting once every four or five years a sufficient mechanism for deciding about laying pipelines or building power plants? What resources does it take to have access to an inquiry?

These questions open up profound political issues about the nature of society and the role of education in it. Curricula that focus on science and social issues will be faced with conflicting pressures on what aspects of the issues to discuss, how much to encourage students to become involved and how closely the decision making mechanisms of society should be examined.

ORGANIZATIONAL ISSUES

If a decision is made to include a science, technology and society focus in a science curriculum then, in addition to the content issues discussed in the previous section, various organizational issues also arise. These are grouped loosely around three questions: for which levels should materials be produced, what type of materials should be produced, and how should they be produced?

Level

To date, the major science, technology and society curricula that have been produced have been aimed at secondary pupils and university students. Can aspects of science, technology and society issues be made appropriate for use in elementary schools?

The B.C. Hydro energy materials (Spratt) and the USA Unified Science and Mathematics for Elementary Schools (USMES) project (Unified Science and Mathematics, 1973) are examples of functioning curricula that introduce elements of STS into the elementary grades. USMES encourages students to define a problem that interests them, to develop a solution and to implement that solution. Examples of problems that have been worked on are the testing of consumer products, the development of a new soft drink, the design of classroom furniture and the elimination of lunch lineups.

Although it is possible to introduce an STS focus at the elementary level, it is crucial that it be introduced by the junior secondary level. In British Columbia many students take their last science course in junior secondary schools (grades 8-10). Students should not leave school believing that science is divorced from real life or believing that science and technology can solve all the problems of the world with enough time and money or that science and technology are the sole cause of problems associated with pollution and technological change. *Science: A Way of Knowing* (Aikenhead and Fleming, 1975) and *The Separation of Substances* (Roberts, McLeod and Orpwood, 1981) are two Canadian examples of curricula with a science, technology and society emphasis which have been successfully tried at grades 10 and 9 respectively.

Types of Material

There are several interrelated issues concerning what types of material should be developed. Should materials for a whole course be developed or should materials for part of a course be developed (a third of a year long science course for example)? Alternatively, should materials be produced that would act as supplementary material for an existing science course – illustrating the way in which a topic such as heat, energy, or genetics could be related to society? The English *Science and Society* (Lewis, 1981) course, by producing a series of modules, has attempted to incorporate enough flexibility to meet any of these three arrangements. The Exeter conference participants agreed that completely new courses should not be created, but rather there should be a 10% infusion of material of societal and ethical character into the present courses (Exeter Conference, 1980). In contrast, Aikenhead argues that science and society issues should dominate science teaching and the 'pre-professional' training as a scientist should be presented as an option (Aikenhead, 1980).

Science, technology and society issues transcend subject boundaries. Should they just be the preserve of science teachers? Should integrated courses taught by an interdisciplinary team be developed? It would be easy to say 'yes', but the difficulties of fitting such a course into the present structure of Canadian schools is enormous. The result is that courses developed by social studies teachers such as *The Technology Connection* (Botting, Gerrard and Osborne, 1980) have no science content and courses such as *Science: A Way of Knowing* (Aikenhead and Fleming, 1978), that introduce disciplines other than science, do not do justice to the complexity of those other disciplines. Lucas (1980) raises the question of how competent science teachers are as historians, aestheticians, political scientists and economists. More importantly, will their world view as empirical experimenters seriously distort the nature of historical understanding and aesthetic judgement, thus distorting the questions asked so that they are no longer recognizable as aesthetic or historical?

A third question about the type of material is the mix between local and general issues. Should the problems of Eurasian milfoil in the Okanagan be of concern to an inner city student confronted by air pollution? The question, however, need not be construed in an either/or way. Rather it could be thought of in pedagogical terms. What issue can interest a group of students? What issues can be used to extend students' horizons beyond their local community?

Should materials be developed around case studies of particular problems or should they revolve around abstract principles of the interaction between science and society? A case study of the British Columbia Royal Commission of Inquiry on Health and Environmental Protection – Uranium Mining, for instance, could be used to discuss the issue of the neutrality of science as well as other issues. Alternatively, the neutrality of science could be taken as a topic by itself and reference made to a series of events both contemporary and historical. Again the issue need not be either/or, but what is an appropriate mix and order of development?

Production of Materials

Materials can be produced at many levels – from school, to school district, as well as regionally, provincially, nationally and internationally. The Exeter conference recommended a national network of science resource centres which would act as development, receiving and distribution centres regionally and nationally (Exeter Conference, 1980). Given the changing nature of social issues it is likely that materials, however they are initially produced, will have to be frequently updated and a mechanism for sharing the responsibility for that devised. If a major project is funded to prepare materials the question still arises as to how the project should proceed. Should it be centralized or should issues be divided up and contracted out to local groups to research local problems and to prepare material for sharing. *The Technology Connection* (Botting, Gerrard and Osborne, 1980) is an example of a project that used the latter approach.

If funding for a large project is required, from whom should it be sought? Will funds from only one source tend to limit the kind of issues explored to those acceptable to that source as has been suggested happened with energy curricula sponsored by energy corporations (Gaskell, 1981). Along with the traditional sources of funding such as governments, industry and foundations, non-traditional sources such as labour unions might be approached. The curriculum on the experience of workers in the Thetford mines in Quebec developed by Michel Desjardins is an example of a project supported by a union (Desjardins, 1979).

Whatever materials are devised, however, it will be teachers who have to interpret them and make them work. Science teachers today have not been trained to take on this task. The development of materials must go hand in hand with discussions amongst teachers about the issues involved, ways of handling them and a sharing of actual experience as well as more formal workshops and courses.

CONCLUSION

This paper has set out some of the issues surrounding the social context of science and technology and its implications for teaching. It is unlikely that a wide consensus can be developed since so many of the issues involve deep rooted ethical and political assumptions.

A discussion of these issues goes far beyond a discussion of which topic in science should be treated in which year or what is an appropriate balance between lectures and practical work. A discussion about science, technology and society curricula raises issues that science teachers have traditionally been able to ignore – questions about the social context of science, the political nature of curriculum and what it means to educate a person about a social issue. The social context that is encouraging science teachers to adopt a science, technology and society focus also will ensure that these larger questions can no longer be ignored.

REFERENCES

AIKENHEAD, G. S. Science: a way of knowing. *The Science Teacher*, Sept. 1979, 46:6.

AIKENHEAD, G. S. *Science in social issues: implications for teaching.* Science Council of Canada, Ottawa, 1980.

AIKENHEAD, G. S. & FLEMING, R. W. *Science: a way of knowing.* Dept. of Curriculum Studies, University of Saskatchewan, Saskatoon, Sask., 1975.

ASSOCIATION FOR SCIENCE EDUCATION, *Alternatives for science education.* Hatfield, U.K., 1979.

ASSOCIATION FOR SCIENCE EDUCATION, *Education through science.* Hatfield, U.K., 1981.

ANDREW, M. D. Elementary-school science: not a basic in New Hampshire. *Science Education*, January, 1980, 64:1.

ANN ARBOR SCIENCE FOR THE PEOPLE COLLECTIVE (eds.). *Biology as a social weapon.* Minneapolis: Burgess, 1977.

BEATTIE, C. Propaganda and curriculum kits: Ontario Hydro's Nuclear science and technology. *Orbit*, October 1980, 11:4.

BOTTING, D., GERRARD, D., & OSBORNE, K. *The technology connection. The impact of technology on Canada.* Vancouver: CommCept Publishing Ltd., 1980.

DESJARDINS, M. (Project Leader) *Ce matin, à l'école, on parlera des mineurs.* Centrale de l'enseignement du Québec (CEQ) and La maîtresse de'école, University of Montreal, Montreal, P.Q., 1978.

THE EXETER CONFERENCE ON SECONDARY SCHOOL SCIENCE EDUCATION. Phillips Exeter Academy, Exeter, New Hampshire, 1980.

GASKELL, P.J. *The ideological orientation of energy curricula.* Paper presented to the Annual Conference of the Canadian Association of Curriculum Studies, Halifax, June 1981.

GEORGE, D. A. *An engineer's view of science education.* Science Council of Canada, Ottawa, 1981.

GILLIS, P. Early federal regulatory records as potential sources for the history of science and technology in Canada. The case of the sawdust pollution files, 1866-1902. In R. A. JARRELL and N. R. BALL (eds.) *Science, technology and Canadian History*, Wilfrid Laurier University Press, Waterloo, 1980.

GOULD, S. J. *The mismeasure of man.* New York: Norton, 1981.

GREAVES, D. G., & WILLIAMS, P. *Canadians' contribution to science.* Science Department, Toronto Board of Education, Toronto.

HARMS, N. and YAGER, R. E. *What research says to the science teacher, Volume 3.* National Science Teachers Association Monograph, Washington, D.C., 1981.

HARRISON, G. B. The role of technology in science education. In Charles P. McFadden (ed). *World trends in science education,* Atlantic Institute of Education, Halifax, N.S., 1980.

HOBBS, E. D., BOLDT, W. B., ERICKSON, G. L., QUELCH, T.P., and SIEBEN, G. A. *British Columbia science assessment summary report.* British Columbia Ministry of Education, Victoria, B.C., 1978.

HUFSTEDLER, S. M., & LANGENBERG, D. N. *Science and engineering education for the 1980's and beyond.* Prepared by NSF and the Department of Education, U.S. Government Printing Office, Washington, D.C., 1980.

KELLY, A. Retrieving the missing half, in Alison Kelly (ed). *The missing half. Girls and science education.* Manchester University Press, Manchester, 1981.

KNORR, K. D., KROHN, R., & WHITLEY, R. (eds.). *The social process of scientific investigation.* Dordrecht, Holland: D. Reidel Publishing Co., 1981.

LATOUR, BRUNO, & WOOLGAR, S. *Laboratory life. The social construction of scientific facts.* Beverly Hills, CA.: Sage Publications, 1979.

LEWIS, J. L., Project Director. *Science in society.* London and Hatfield, Herts.: Heinemann Educational Books, The association for Science Education, 1981.

LOVINS, A. *Soft energy paths. Toward a durable peace.* New York: Ballenger, 1977.

LUCAS, A. M. Science and environmental education. Pious hopes, self praise and disciplinary chauvinism. *Studies in Science Education,* 1980, 7, 1-26.

MARSHALL, A. R. (ed.). *School technology in action.* London: English Universities Press, 1974.

McFADDEN, C. P. (ed.). *World trends in science education.* Halifax, N.S.: Atlantic Institute of Education, 1980.

MULKAY, M. *Science and the sociology of knowledge.* London: George Allen and Unwin, 1979.

NELKIN, D., & POLLACK, M. Public participation in technological decisions: Reality or grand illusion? *Technology Review,* Aug/Sept. 1979.

PAGE, J. E. *A Canadian context for science education.* Ottawa: Science Council of Canada, 1979.

PREECE, P. Uneven course. *The Guardian,* March 24, 1981.

RAVETZ, J. R. *Scientific knowledge and its social problems.* Harmondsworth, England: Penguin, 1971.

ROBERTS, D. A., McLEOD, P. E., & ORPWOOD, G. W. F. *Separation of substances.* Toronto: Ontario Institute for Studies in Education Press, 1981.

ROSE, H., & ROSE, S. (eds.). *The political economy of science.* London: Macmillan, 1976.

SINCLAIR, B. Forward in R. A. JARRELL & N. R. BALL (eds.) *Science, technology, and Canadian history,* Wilfrid Laurier University Press, Waterloo, Ontario, 1980.

SPRATT, P. J. & ASSOCIATES INC. *Energy education materials.* Vancouver: B.C. Hydro.

SUZUKI, D. *The impact of science and technology on education.* An address given at the Canadian Education Association Convention in Vancouver, B.C., September 1980.

Technology on trial: Public participation in decision-making related to science and technology. Organization for Economic Co-operation and Development, Paris, 1979.

UNIFIED SCIENCE AND MATHEMATICS FOR THE ELEMENTARY SCHOOL (USMES). Durham, N.C.: Moore Publishing Co., 1973.

WOOLNOUGH, B. E. The place of technology in schools. *The School Science Review,* March 1975, 56:196.

YAGER, R. E. *Crisis in science education.* Technical report 21, Science Education Centre, The University of Iowa, Iowa, June 1980.

YAGER, R. E. Science Education, *ASCD Curriculum Update,* September 1981.

Studies in Science Education 9 (1982), 47-64

Science Education for Citizens: Perspectives and Issues

II. Science and Technology Policy and the Democratic Process*

DOROTHY NELKIN

Program on Science, Technology and Society and Department of Sociology, Cornell University

SUMMARY

This paper reviews the issues involved in the demands for greater public participation in science and technology policy. Numerous controversies suggest that the sources of 'participatory politics' lie in the changing public image of science and technology and especially in the changing attitudes toward expertise as a source of political legitimacy. The paper analyzes these sources of conflict and the various 'publics' involved, describing diverse fears about science and technology that lead to participatory demands. While surveys indicate that most people perceive science and technology as instrumental in achieving important social goals, specific concerns persist. The central and pervasive issue – the source of many conflicts – is the question of who controls crucial policy decisions.

As various groups seek greater participation in science and technology policy, governments have expanded participatory channels both within the representative system and through administrative reforms. In addition, participatory experiments outside of official administrative channels have proliferated. Describing experiments in the US and Western Europe, the paper suggests the range of options available to accommodate participatory demands. It also analyzes some of their difficulties, as the complexity of science and technology and the expectations of efficiency associated with technical planning obstruct efforts to develop participatory procedures.

The demands for participation can affect the application of resources to research, the strength of research institutions and the way scientists choose their topics and conduct their work. And participation can influence the general climate – political,

---

* *Editor's note:* Professor Dorothy Nelkin's paper was commissioned by the National Science Foundation as background for the first *Five-Year Outlook* on science and technology (NSF Publication 80-30, pp. 483-92, 1980). The views expressed by the author are, however, her own and do not necessarily reflect the views of the National Science Foundation or the U.S. Government.

social and intellectual – in which research takes place. Thus its implications warrant special attention in the coming years.

INTRODUCTION

Everywhere symbols of progress are under public scrutiny. Technologies of speed and power – airports, highways, nuclear plants – provoke antagonism as local communities protest against noise and disruption. Science-based programs such as genetic screening are a source of public debate. And important areas of research face persistent opposition: note, for example, disputes of foetal research, recombinant DNA, and studies of the genetic origins of human behaviour. Technical problems that were once considered the preserve of experts are increasingly forced into the political arena as many interests seek greater control over the direction of science and technology.[1]

Until recently, most questions of public control focused on technological applications, but public scrutiny has come to rest on science as well. Given the policy importance of many areas of scientific research and the growing concern in the biological sciences with basic life processes, such scrutiny is inevitable. Indeed the relationship between science and the public appears to be in the process of significant renegotiation.

Despite the intensity of some disputes, few people seek to impose major restrictions on science and its applications; most areas of science and technology are valued as instrumental in achieving important social goals. Rather, the negotiation is over *who* should participate in establishing policies and controls, how these controls will be organized, and how much they should influence decisions concerning the direction and conduct of research. Reflected in these questions is a troublesome feature of contemporary society – the impact of increased complexity and specialization on the decision-making process. The power afforded to those who control technical information reduces public control over many public policy choices, and technical complexity appears to limit effective political choice. This concern is ubiquitous in the controversies over science and technology. The key slogans in these disputes are 'public accountability of scientists,' 'demystification of expertise' and 'lay participation.' Local groups demand a voice in the location and design of nuclear power plants. Patients seek greater control over their medication. Parents insist on influencing the science textbooks used in schools. Consumers raise questions about the validity of the data that back government regulation of drugs such as cyclamates, saccharin and laetrile. Citizens seek to participate in shaping the rules and standards that control science and technology or the conditions of work in the laboratory.

Participatory demands have focused both on the conduct of research (the recombinant DNA and foetal research disputes) and on its public consequences (research on genetic manipulation or on the sources of criminal violence). Indeed, a new field, 'the social assessment of science,' is emerging to examine 'the involvement of non-scientists in the assessment, judgment and criticism of science.'[2]

While the concern in this review is more with policies that affect the conduct of research than with the management of technology, it includes examples of the latter. It is often hard to distinguish science from its applications, and public concern about technology extends to science, especially in those areas perceived to have eventual application. People are clearly more concerned about technology than about science, but when asked in a public opinion survey whether it is more important for society to control science or technology, 59 percent responded that both must be controlled equally (20 percent that neither should be controlled at all).[3]

This paper, then, analyzes the politics of participation in both science and technology policy. It describes the sources of participatory demands, the existing procedures and some recent experiments in accommodating those who wish to participate, some of the obstacles to greater participation, and, finally, some of the potential implications of greater public involvement.

SOURCES OF PARTICIPATORY POLITICS

Demands for greater public involvement in science and technology reflect the convergence of a heightened sensitivity to the environmental and social implications of science and technology with a changing view of expertise. These are the preconditions for participatory politics as people seek greater control over decisions that affect their lives.

Changing images of science and technology

Attitudes toward science and technology are ambivalent. Optimistic expectations about potential social good are mixed with concern about undesirable consequences. Surveys indicate that most people view science as instrumental in achieving important social goals, yet only a small majority (52 percent) of respondents in a 1976 survey said they believed that science and technology have produced more good than harm. By far the greatest perceived benefits were in the field of medicine (81 percent); in other areas – improved living conditions, environmental conservation, energy programs and improved communication – science and technology were reported as beneficial only 10–14 percent of the time. A review of longitudinal data on the public's confidence in people who run institutions found that the proportion of respondents expressing 'a great deal of confidence' in the scientific community declined from 56 percent to 43 percent between 1966 and 1976.[4] However, in gauging the public's esteem for science relative to other occupations in 1976, science ranked second (behind medicine) and engineering third. Public regard for scientists has declined in absolute terms, but this reflects the declining trust in most major institutions. Between 1966 and 1976 those expressing a great deal of confidence in Congress declined from 42 percent to 14 percent, the heads of major corporations from 55 percent to 22 percent, the US Supreme Court from 51 percent to 35 percent, and educators from 61 percent to 37 percent. In this context scientists have fared rather well.

But opposition to specific projects persists. Science and technology are often blamed for environmental pollution, loss of privacy and civil liberties, the impersonal character of medical care, the routine character of work, and the threat of greater social control.

Concerns about science and technology extend beyond the fear of risk. Some critics (e.g. those opposing foetal research or the teaching of evolution) feel that science has ethical implications that threaten deeply held personal beliefs. Others worry about the potential misuse of scientific findings: for example, critics of research on recombinant DNA, on the XYY chromosome and on the relationship between genetics and intelligence question the implications of relating genetically mediated characteristics to human behaviour. Biology, they claim, is 'a social weapon.' 'Can future generations cope with the possibilities science opens up today?' Still others are concerned about equity both in the allocation of resources to science and technology and in the distribution of social and environmental costs.

It is often argued that changing attitudes towards science reflect disappointed expectations. Atomic energy and the space program brought science from the obscurity of the university laboratory to the forefront of American consciousness, creating optimistic expectations – the so-called 'Moon-Ghetto syndrome'. Given enough support, science and technology can solve all problems.[5] Yet the 1960s also brought the realization that science and technology not only failed to solve social problems but often contributed to them.

The changing image of science and technology also reflects reaction to the increased role of the Federal Government in this sector. The rate of technological change, the scale of scientific and technical projects, the rapid diffusion of technology to new areas, and the high costs associated with R&D have necessitated increasing Federal commitment to develop and regulate many technologies and some areas of scientific research as well. These have essentially moved from the private to the public sector.

This has happened at a time when public interest in playing a role in major policy decisions at all levels has reached a high point. Science and technology, of course, have not been immune. Demands for public accountability and questions about the appropriate focus of authority in science and technology policy reflect a more general loss of confidence in established institutions and a concomitant concern with public or consumer influence.

Changing images of expertise

As technical knowledge assumes growing policy importance, scientists and engineers are increasingly active in public policy decisions through advisory boards, special commissions, staffs, and consultant groups.[6] Federal Government expenditures for consultants have been estimated at over $1.8 billion a year. Moreover, there has been a general evolution from ad hoc advisory activity to the institutionalization of an 'intellectual technocracy.' Federal Government employment of scientists grew by 49 percent from 1960 to 1970; for social scientists the increase was an even greater 52 percent. (Total Federal Government employment grew by only 30 percent during the same period.)

The implications of the growing policy role of expertise are not clear. Some perceive evidence of a growing technocratic elite – a new source of power with decisive influence over both politicians and the public.[7] Political power, it is argued, has shifted significantly from political and corporate decisionmakers to 'knowledge elites' who derive their authority from the cultural emphasis on rationality, efficiency and technological progress, and from the specialization inherent in bureaucratic organization.

An alternative view sees the technical elite essentially as a 'mandarin' class, beholden to the existing establishment and commanding little or no independent power.[8] Experts, it is claimed, use their specialized knowledge to serve the established institutions in industrial society. They are said to be effective only insofar as politicians and entrepreneurs allow them to be, and they pose no real threat to entrenched forms of power. It is further argued that existing institutions legitimize themselves by enlisting technical expertise and using it selectively to give the appearance of objectivity, to support predetermined decisions, to maintain secrecy, or to 'buy time' when opposition is anticipated.[9]

Both views of the experts' role have increased apprehension about an erosion of democratic values. Metaphors of 'the priesthood' or 'the new Brahmans' are used to describe the function of the 'knowledge elite' in a social system where authority is based on information, and many policy choices are reduced to technical decisions.[10] The power afforded to those who control technical information reduces public influence. Thus, just as people are more aware of the potential harm associated with science and technology, they also feel they have fewer ways to directly influence them. This structural dilemma creates demands for greater public involvement.

THE 'PUBLIC' AND THE PARTICIPATORY IMPULSE

Controversies over science and technology involve a variety of groups concerned with greater influence over the direction and control of science and its applications. As they organize, their concerns are translated into participatory demands.

Who is involved?

The most obvious 'public' concerned about science and technology is those persons who are directly affected by land expropriation, immediate risk, or rapid local economic, environmental or social change. Residents of urban neighbourhoods often claim that technological developments neglect their needs. They question the justice of the anticipated distribution of costs and benefits from a technology. Can any reduction in some citizens' welfare be justified by greater advantage to others? Can the magnitude or intensity of harm borne by neighbours of a noxious facility be reasonably incorporated into cost-benefit calculations? These questions are expressed in organized opposition to the expansion of airports and the siting of highways or power plants. Recently similar arguments have confronted plans for siting biology laboratories to host recombinant DNA research. Indeed, most participatory demands come from the 'neighbours' of science and technology, those directly affected by a planned project and unable to avoid its present impact or potential risks.[11]

In addition, a well-defined 'concerned public' includes direct recipients of such professional services as health care. Mental or medical patients are directly affected by the availability of new drugs, new biomedical technologies, and trends in the use of health care techniques.[12] They may also be subjects of clinical research. Here the demands for participation, based on the rights of individuals to have some voice in their own treatment, are often expressed in proposals for changes in professional-client relationships.

A far more vaguely defined public is made up of the consumers of the products of science and technology. Here the participatory impulse is often reflected in protest against government regulation of technology. The laetrile dispute and the debates over regulation of saccharin and cyclamates raise questions about government intrusion and the limits of individual choice. In such cases, the opportunities opened up by science and technology and the potential risks involved in innovation exacerbate this classic political dilemma.

Other groups critical of science and technology share rather global concerns based on ideological or moral principles. These include members of major environmental and public interest associations who seek to influence national policy.

Finally, an important source of criticism has come from the scientific community itself. Many scientists became politicized during the 1960s. At that time, they focused on anti-war activities and the issue of military research in universities. More recently, their attention has turned to the environment, nuclear power or biomedical research. These scientists question the potential risks in areas often obscured from public knowledge.[13]

As differences between experts rise to public visibility, science no longer appears as an objective and compelling basis for policy. Disputes among experts, encouraged by the intrinsic uncertainty concerning the impact of science and technology, call attention to this limited ability to predict potential risks. Controversy thus demystifies expertise, exposing the non-technical and political assumptions that influence technical advice and encouraging the transfer of problems from the technical to the political arena.

From public concern to participatory demands

Technological controversies are marked by the proliferation of citizen groups. Most are temporary coalitions formed to challenge specific decisions, often disbanding once the issue is resolved. But some groups maintain themselves with a core of activists who remain interested in other projects affecting the community and who can mobilize a larger constituency when specific issues arise.

Sustaining these local groups are the large national associations such as the Sierra Club and Friends of the Earth, whose membership has more than tripled since the 1960s. Their relatively stable constituency can be mobilized to intervene in diverse technical areas, and they seek to increase public participation in areas of science and technology that present potential risk. They were, for example, among the active participants in the recombinant DNA dispute.

Consumer protection and public interest science groups have also proliferated. Such organizations as the Centre for Science and the Public Interest, the Centre for Concerned Engineers, the Coalition for Responsible Genetic Research, the Clearinghouse for Professional Responsibility, and Science for the People call attention to the social impacts and political dimensions of science and technology,[14] and they try to provide citizen groups with the technical expertise necessary to challenge policy decisions.

The interest of these various groups extends beyond specific policies to the broader issue of decisionmaking power. Controversies are pervaded by questions of responsibility and control; 'expert accountability' is a central theme. The demands of local community groups often resemble a kind of 'mini-nationalism,' as they seek to protect themselves by greater local control against the intrusions of technology. Expertise, they claim, should rest with those affected: 'We need no experts'; it is an 'arrogant assumption' to leave decisions to scientists. Thus citizen groups call for better information, provisions for 'counter-expertise' and greater opportunities for participation.

PARTICIPATORY MECHANISMS AND ADMINISTRATIVE REFORMS IN SCIENCE AND TECHNOLOGY POLICY

Demands for greater participation have coincided with congressional qualms about the increasing power of administrative agencies. To sustain the authority of the representative system over decisions in technical areas, the Congress has built up its own technical competence, and it has also imposed legislative requirements on agencies to involve citizens more directly in the formulation and implementation of science and technology policies.

Participation and the Representative System

Increasingly involved in decisions concerning science and technology, Congress has greatly expanded its technical staff. Between 1947 and 1976 the combined staffs of the Senate and House increased from 2,513 to 13,272. Staff appointments have included specialized science-trained consultants who gather technical information and select technical witnesses for public hearings. The many hearings on recombinant DNA, for example, were largely structured by professional staff through the selection of key witnesses. A number of these hearings were specifically organized as a means to brief special congressional committees on various technical and political aspects of this controversial issue.

To improve its technical competence, Congress has also established several research services.[15] The Congressional Research Service was created in 1970 to provide information on special issues. The Office of Technology Assessment (OTA) was established in 1972 to assist Congress in evaluating and planning specific technologies. These technical services allow Congress to re-assert legislative control and oversight over issues that have previously been delegated to administrative agencies.

The primary congressional response to anxiety about democratic representation has been through legislation. The Airport and Airways Development Act, the Federal Water Pollution Control Act, the Coastal Zone Management Act, the Highway Safety Act, the National Environmental Policy Act, and the Energy Re-organization Act all contain requirements for greater direct participation in administrative agency decisions.

Administrative channels of participation

Administrative agencies are a major arena for political action, often replacing legislative bodies in defining policy problems and devising their solutions.[16] Yet agency commitment to rational, efficient decisionmaking usually precludes significant public involvement, except in a few highly politicized proceedings such as the power plant siting hearings of the Nuclear Regulatory Commission.[17] Participatory reforms are mostly intended to expand the information available to the public and to channel information about public preferences to decisionmaking agencies. However, some procedural reforms seek to open the administrative process to negotiation and compromise, allowing public representatives to take part in the development of policies. I will briefly review some of these procedures, suggesting why critics often dismiss them as inadequate and seek participation through other means.

Participatory reforms have provided greater public access to data and reports that underlie the decisionmaking process. The Administrative Procedures Act requires administrative agencies to publish proposed rulemaking in the *Federal Register* and invite public comment. These comments are then taken into account when final regulations are developed. The *Register* contains drafts of controversial proposals; for example, HEW published early drafts of proposed regulatory guidelines for the use of human subjects in research in order to solicit public comments and to test public acceptability of HEW procedures. The National Research Act of 1974 extended this use of the *Federal Register*, as a forum as well as a bulletin board, by creating the National Commission for the Protection of Human Subjects of Biomedical and Behavioural Research to advise HEW. It required the Secretary of HEW to publish the Commission's reports and recommendations prior to announcing his proposed rules and to respond if he failed to follow them.

The Freedom of Information Act further extended public access to government reports, as did the requirements for Environmental Impact Statements (EIS). Under the EIS requirements, agencies must publicize the existence of documents and actively disseminate them. This model has generated proposals for 'Scientific Impact Statements' that would similarly evaluate the potential effects of research and solicit public review.

These participatory channels can provide useful information and also inform decisionmakers of citizen concerns, but critics contend that considerable initiative, money and access to expertise are necessary to seek out and to utilize useful material. The *Federal Register* is available in libraries and is indexed, but with 60,000 three-column pages per year it is a cumbersome document. Agencies must disclose information on request, but sometimes charge search and copy fees. Citizens unfamiliar with what is available or lacking access to expertise are often unable to request material with sufficient specificity, and crucial material on controversial topics is often withheld as proprietary information.[18] Thus, it is argued, while legislative reforms provide greater legal access to information, they are intended more to reduce conflict than to devolve power. More collaborative modes of participation include having citizen representatives, not simply as informants, but as partners with some power to exercise direct influence.

Advisory boards are a frequent channel for such collaborative participation. In 1975, 45 agencies employed 1,267 advisory committees with 22,246 members. However, a 1976 survey of 16 Federal energy agency advisory boards reported that nearly 50 percent of the board members were industry representatives, while consumer and environmental representation comprised 4 percent and 3 percent respectively.[19] Agencies justified this balance by arguing that citizens' groups were not interested, lacked technical qualifications, or were simply inappropriate; citizens' groups, however, charged agencies with trying to close their deliberations to 'outsiders.' Their arguments have had increasing effect on increasing citizen representation on advisory boards.

For example, the Federal Energy Administration advisory committees doubled their consumer and environmental representation to 10.8 percent and 7 percent respectively. The FDA has paid consumer representatives elected by consumer groups on its advisory panels. Of the 18 members of the National Council on Health Care Technology appointed to assess the safety, the effectiveness and the social impacts of health technologies, two must be from law, one from the field of ethics and three from 'members of the general public who represent the interests of consumers of health care.' The National Institutes of Health (NIH) has experimented with consumer representation on advisory panels that are responsible for reviewing research proposals. NIH uses two stages of review: the first by study sections composed of scientists who judge the technical competence of proposals, the second by advisory councils composed of scientists and informed laymen who decide the allocation of funds on the basis of NIH priorities and social considerations.

Disputes over controversial areas of biomedical research have brought expanded public participation in the NIH advisory groups. The 25 people composing NIH's Recombinant DNA Advisory Committee, for example, include several lawyers and ethicists, a scientist from a public interest organization, and several non-scientists who have been actively critical of existing controls over this research. Similarly, the National Commission for the Protection of Human Subjects of Biomedical and Behavioural Research includes five scientists, three lawyers, two ethicists, and one public representative. It has sought to enhance public involvement through open meetings where public comment was encouraged, through surveys of national opinion to evaluate its own effectiveness as perceived by the public and through the creation of five independent public information centres. In addition, NIH and NSF require that institutuions seeking Federal funds form Institutional Review Boards (IRBs) to monitor all research proposals involving human experimentation. These IRBs include lay participants. A recent study found that most members (50 percent) were biomedical scientists, 21 percent were social scientists, and the rest included administrators, lawyers, clergymen and other non-scientists.[20] New policy proposals call for including more lay members on the IRBs and opening IRB meetings to the public.

Some see this form of participation as a desirable way to forestall potentially harmful consequences of research and to ensure scientific work of greater social utility. But others fear that participation will lead to administrative delays, excessive constraint based on short-sighted goals and, ultimately, to dangerous social control over scientific inquiry. Thus, the response to legislative mandates for greater participation proceeds with caution.

OTHER CHANNELS OF PUBLIC INFLUENCE OVER SCIENCE AND TECHNOLOGY POLICY

The structure and responsibilities of government institutions place important constraints on meaningful public participation through administrative procedures. Thus critics of science and technology have developed their own channels of participation through the courts and special referenda, and this in turn has inspired a number of participatory experiments, outside the usual government channels but intended to increase public influence over government policy.

Litigation and Referenda

Litigation has been a major means for citizens to restrict and direct technological change.[21] The courts may define responsibilities for damages caused by technology;

they can improve injunctions against proposed technologies that may be harmful, and they can galvanize administrative agencies and regulatory commissions into more effective action by re-affirming standards.

The ability of citizens to use the courts has expanded with the extension of the legal doctrine of standing which determines who has a right to be heard. 'Standing' to sue varies from state to state, but the rules of standing have generally been liberalized to allow a private citizen without an alleged personal economic injury to present a grievance as an advocate of the public interest. Moreover, in environmental litigation, the courts have accepted as cause for standing not only damage to property rights but some of the more subtle health and aesthetic impacts of technology.

Citizen litigation as a means of policy influence has focused mostly on technological applications, but occasional cases – e.g. the Boston 'grave-robbing' trial of medical researchers studying aborted foetuses – focus on science as well. Medical malpractice suits may be extended to clinical research or genetic experimentation. And the growing concern over the adequacy of safety precautions in the laboratory opens possibilities for legal action.

The role of the courts in cases associated with science and technology poses considerable problems. Despite a well-developed system of using expert witnesses, the courts cannot easily deal with esoteric scientific information that involves uncertainty. Many of the problems of science and technology require evaluation of potential risk at some future date. Weighing cancer risks, for example, requires judgments based on statistical evidence. Yet judges are accustomed to ruling on the basis of precedent. Moreover, developments in science and technology raise problems that require re-analysis of legal principles. What, for example, is the appropriate role of law in controlling genetic experimentation? How can the courts deal with new questions that arise in the wake of expanded clinical research without stifling scientific progress? These are some of the issues confronting the courts as they are increasingly used to influence decisions about science and technology.

The referendum is a prominent and growing feature of the United States political landscape and, significantly, technological decisions such as airport expansion, nuclear plant siting and nuclear waste disposal plans are appearing on ballots. The direct citizen vote is a form of participatory democracy within representative governments, and it is intended to preempt administrative authority. While using referenda for technical issues poses problems of representation, adequate information and co-optation, its growing popularity suggests an interest in shifting technical decisions to a more participatory framework.

Participatory Experiments

The current surge of participatory demands reflects the decline in public confidence in decisionmaking authorities. Concern with this trend has shaped a number of experimental efforts to establish the procedural conditions that would encourage public acceptance of technology and restore trust. For example, agencies search for ways to gain information about actual public preferences. Opinion polls are the most common technique, but in 1970 the US Forest Service employed an instrument called 'code-involve' to uncover public attitudes about its proposed use of DDT to protect Douglas Firs.[22] Code-involve is an applied content analysis system designed to transfer large quantities of information from written statements in diverse sources (e.g. editorials, petitions, letters) into a condensed form for policy review. Condensing scattered statements into clusters of opinions, the system offers a wider spectrum of attitudes than may emerge from other procedures such as public hearings, and the frequency of a given view as it appears in written statements provides a measure of its prevalence.

Some 'quasi-experiments' attempt to use systematic observations of the actual behaviour of individuals as evidence of policy choices. For example, to assess the social impact of power plants, investigators measure actual reactions to siting policies as an indicator of public preferences.[23] Participation in such experiments is random and mediated by the procedure. The only questions answered are those that are raised by the researchers and their sponsors. Nevertheless, social research techniques are increasingly exploited as a surrogate for direct involvement – as a way to increase public influence while avoiding the problems of representation inherent in many participatory procedures.

A number of experiments employ mediation procedures. Modelled after industrial-labour negotiations, they are intended to promote constructive dialogue among contesting parties to a controversy. The process is based on the voluntary participation of groups concerned about a project; they meet to debate the issues with a third party who facilitates arbitration of the dispute. Mediation procedures have helped to reach settlement in several environmental cases.[24]

Another participatory procedure emerged from the recombinant DNA dispute when citizen review boards formed to advise the city councils in several communities on policies for allowing the research to go on. The first of these, in Cambridge, Massachusetts, was organized on the principle that decisions about risks and benefits are questions not for scientists but for laymen, and that laymen are able to face technical matters, educate themselves, and reach just decisions.[25] This review board, composed entirely of non-scientists, discussed complex questions about the risks of DNA research for four months and, with a modification requiring local monitoring, approved the research under the Federal guidelines set down by the National Institutes of Health. A similar citizen review structure has been proposed by a study group at the Oak Ridge National Laboratory to resolve nuclear siting disputes.

Some European Models[26]

Several European experiments are worth noting. In the Netherlands, an elaborate public inquiry system was developed on the principle that the public must be consulted on all decisions affecting the environment. Government plans are preceded by the publication of 'policy intentions' dealing with political and philosophical questions: the objectives of growth, the goals of particular technological projects and their likely impacts. These are widely distributed for public comment. Local governments organize discussion groups, information evenings, and photo and sound shows on the plan. Television programs present alternatives and encourage people to send in their written comments. Reactions are analyzed by a representative advisory group, and the appropriate minister must answer criticism and either reformulate or justify his policy. The entire dossier developed through this process serves as a basis for parliamentary decisionmaking.

The Austrian government set up a series of structured public debates between scientists with opposing views on nuclear policy. The purpose was to highlight controversial dimensions of the nuclear program and to clarify the areas of persistent disagreement. This was mainly intended to inform parliament but also to engage public reaction.

In 1974, disturbed by the growing anti-nuclear movement the Swedish government initiated an experiment in public education. Using an existing system of study groups managed by the principal popular organizations and political parties, the government financed a program to inform broad segments of the public about energy and nuclear power. The program involved some 8,000 study circles, each with about 10 members who met together to discuss those energy-related questions they felt to be most important.

The Burgerdialog in Germany, first organized in 1974, represents a similar effort to involve broad sectors of the public in an information program. Organizations such as churches, unions, and adult education groups have been funded to organize discussion groups and meetings which include speakers both for and against nuclear power. The goal is to strengthen confidence in the democratic process and to restore public confidence in the adminstrative authorities.

These information efforts are for the most part intended less to ascertain public opinion than to inform citizens about the value of specific technology policies and to convince them that risk is minimal. Informing the public is equated with participation, even though its aim is to create more favourable attitudes. While in most cases opposition persists, such experiments are important to observe for the insights they provide into diverse ways of accommodating greater public involvement.

SPECIAL PROBLEMS OF PARTICIPATION IN SCIENCE AND TECHNOLOGY POLICY

Democratic ideology requires participation in decisionmaking by affected interests. But in the arena of science and technology there are special problems in expanding political choice – for citizens seeking to influence policies involving complex technical material, for bureaucracies responsible for efficient technological development, and for scientists concerned about the progress of research.

Problems of Citizen Influence

Citizen involvement in science and technology policy depends on many of the same factors that affect political participation: leadership, community organization, access to the media, and the visibility and urgency of the immediate issue. However, other factors, such as the availability of information and the distribution of expertise, assume special importance in this policy area. In order to have any real influence in the process, citizen groups must cope with complex and often uncertain technical material. And they must have access to experts who can help to analyze the material and maintain control of the information and grasp of the policy choices. Thus access to technical resources is a key problem for citizen groups.

A related problem lies in the complex network of decisions that contribute to technical policies. Citizens seeking to influence nuclear energy policy, for example, must focus their resources on very diverse areas: Federal research policy, licensing procedures, fuel supply, and waste management decisions. But also they must try to influence state regulations on utility rates, permit procedures, Federal and state environmental legislation, and local government land use regulations. Participation on all these fronts is costly, especially since those who intervene must be able to present an informed and technically valid case.

The fuzzy boundaries between the technical and political dimensions of science policy compound the difficulties of expanding public choice. Too often political issues, such as the tradeoffs between risks and benefits, are defined as technical, and technical questions of feasibility become confused with political acceptability.

Finally, administrative ambivalence may limit public choice. Agencies control the agenda of hearings and select the members of committees. The timing of public involvement – often late in the decision process – puts citizens at a disadvantage where they can only react to proposals already accepted and even already underway.

Administrative concerns

Participation presents administrative authorities with a dilemma. They have likely judged the propriety of their policies according to their contribution to general economic growth, only to discover that their activities are perceived as allied to special interests. They have likely assumed that legitimacy would flow from their technical competence, only to find critics insisting that legitimacy must rest on public consent. Expertise remains central to insuring the efficiency of administrative and legislative procedures, yet deeply rooted democratic values hold that public consent is a 'right,' and that procedures including more direct citizen involvement are intrinsically 'better'.

Administrative agencies try to avoid political conflict by following procedures that are limited to those who share common assumptions. Demands for involvement by citizens' groups with different assumptions disrupt procedures, preclude accommodation, and raise political dilemmas. Participatory measures, it is feared, will encourage endless demands from private interests or from self-appointed public representatives who lack the technical knowledge necessary to assess decisions.[27] This will lead, they fear, to impossible expectations for risk free technologies and unresolvable polarization: 'environment vs. jobs,' 'local costs vs. regional benefits', 'individual choice vs. public interest'. There is concern that such participants will seriously obstruct the decisionmaking process, causing costly delays and precluding the long-range perspectives necessary for effective technical planning. Indeed, those who manage the scientific and technological enterprise feel constant tension between the ideal of participation as a source of legitimacy and its practical consequences.

THE IMPLICATIONS OF PARTICIPATORY POLITICS

> Scientist, regulator, lawyer, and layman must work together to reconcile the sometimes conflicting values that underlie their respective interests, perspectives, and goals.[28]

As governments fumble to accommodate participatory demands in different political and administrative situations, difficult questions remain. What form can lay participation take in complex technical areas? Who should be involved? What are its implications for the representative process? And, of particular concern to this report, what are the implications of greater lay involvement for the application of resources to research, for the strength of the research institutions, for the way scientists choose their topics and conduct their work, and for the general climate – political, social and intellectual – in which research takes place?

Perceptions of the consequences of greater participation reflect quite different political perspectives on the nature of the scientific enterprise and the appropriate relationship between science and the citizen. Some argue that the layman, unable to deal with the complex technical material necessary to evaluate science and technology, must leave responsibility to the scientists. Others claim that the political and moral implications of science and technology are matters of central public concern that require political, not technical, competence: hence the citizen must be involved.

Many scientists have interpreted demands for participation as an indication of anti-science attitudes. They fear that lay involvement would threaten their autonomy and bring external controls that would infringe on freedom of inquiry and virtually paralyze the research process.[29] However, experience suggests that even the critical public does not want to stop either science or technology, although particular projects may be under attack. Lay involvement in the NIH advisory review boards has not destroyed the grant review system; study sections continue to review the scientific merit of individual proposals and control the quality of research. Although the existence of institutional review boards to monitor human experimentation is still viewed by many scientists as an 'unwarranted intrusion' that impedes research, lay participation in these boards has not significantly obstructed research. Indeed non-scientists have been generally less active and less influential than scientists.[30] Even the Cambridge Review Board supported the continuation of recombinant DNA research under the NIH guidelines, clearly accepting the premises of the scientific community about the value of research. And, in the end, the intense public concern over this issue abated, while control remained with the NIH as before.

Attitudes toward participation also remain ambivalent among those with political concerns. Some criticize participatory procedures as simply another means to maintain the existing structure of influence. Participatory procedures are easily co-opted; token participation can simply reinforce the status quo, providing means for informed consent rather than expanding democratic choice. Others suggest that participation provides a means to protect minority interests and to include a wider range of issues in the policy agenda. These arguments develop in all policy areas – and as science and technology assume growing social and political importance, they are no exception. Democratic ideals imply that science policy be subject to greater public scrutiny and political control. Indeed, a fundamental source of public concern about science and technology is their implication for political choice. Accommodating these demands of democracy while maintaining the best of scientific learning is a key and growing challenge that will warrant careful attention over the coming years.

NOTES

1. For a review and analysis of these conflicts, see DOROTHY NELKIN. ed., *Controversy: Politics of Technical Decisions.* Beverly Hills: SAGE Publications, 1979.
2. MENDELSOHN, EVERETT, and WEINGART, PETER. 'The Social Assessment of Science: Issues and Perspectives'. In MENDELSOHN, E., NELKIN, D., and WEINGART, P., eds., *The Social Assessment of Science.* Conference Proceedings, University of Bielefeld, 1978.
3. OPINION RESEARCH CORPORATION. *Attitudes of the U.S. Public Towards Science and Technology.* Study III (September 1976), p. 51.
4. The above data on public attitudes are from the National Science Board, *Science Indicators 1976.* USGPO (1977), pp. 168-182. Similar ambivalence shows up in European surveys. See Commission of the European Communities, *Science and European Public Opinion,* Brussels, 1977. A more recent survey focusing specifically on medical research shows greater confidence in this field than others. Most respondents felt medical research has changed life for the better (very much better – 59%, somewhat for the better – 34%). But 49% agreed that in deciding what to do, scientists are more concerned with their own research interests than with public benefits; National Commission for the Protection of Human Subjects. *Special Study.* DHEW Publication No. (OS) 78-0015, 1978.
5. NELSON, RICHARD, *The Moon and the Ghetto.* New York: W. W. Norton, 1977.
6. GIANOS, P., 'Scientists as Policy Advisors: The Context of Influence', *Western Political Quarterly* (September 1974), pp. 429-456; BENVENISTE, G., *The Politics of Expertise,* Berkeley: Glendessary Press, 1972.
7. MEYNAUD, JACQUES, *Technocracy.* London: Faber and Faber, 1968; ELLUL, JACQUES, *The Technological Society,* New York: Alfred A. Knopf, Inc., 1970.

8. NOBLE, D., *America by Design*, New York: Alfred A. Knopf, 1977: WINNER, L., *Autonomous Technology*, Cambridge: MIT Press, 1977: McCRAE, D., 'Science and the Formation of Policy in a Democracy', *Minerva* (April 1973), pp. 228-242.
9. PRIMACK, J. and VON HIPPEL, F., *Advice and Dissent: Scientists in the Political Arena*, New York: Basic Books, 1974; BENVENISTE, G., *op. cit.*: LAKOFF, S., 'Scientists, Technologists and Political Power'. In ROSING, I. S., and PRICE, D., *Science, Technology and Society*, Beverly Hills: SAGE Publications (1977), pp. 355-392.
10. KLAW, SPENCER, *The New Brahmans: Scientific Life in America*, New York: Morrow, 1969; LAPP, R., *The New Priesthood*, New York: Harper and Row, 1965.
11. For example, see NELKIN, DOROTHY, *Nuclear Power and Its Critics*, Ithaca: Cornell University Press, 1971: NELKIN, DOROTHY, *Jetport*, New Brunswick: Transaction Books, 1975. For the propensity to protect when unable to avoid problems, see HIRSCHMAN, ALBERT, *Exit, Voice and Loyalty*, Cambridge: Harvard University Press, 1970.
12. ALFORD, R., *Health Care Politics*, Chicago: University of Chicago Press, 1975.
13. MAZUR, A., 'Disputes Between Experts', *Minerva*, XI (1973), pp. 213-262.
14. See for example, 'Ann Arbor Science for the People Editorial Collective', *Biology as a Social Weapon*, Minneapolis: Burgess, 1977.
15. CARPENTER, RICHARD, 'Information for Decisions in Environmental Policy', *Science*, 168 (12 June 1970), pp. 1316-22; and CASPER, BARRY M., 'Scientists on the Hill'. *Bulletin of the Atomic Scientist* 33, November 1977, pp. 8-15, for discussion of scientific advice to Congress; FOX, HARRISON, Jr., and HAMMOND, SUSAN W., *The Invisible Force in American Lawmaking*, New York: The Free Press, 1977.
16. For a general discussion of this problem see LOWI, THEODORE, 'Four Systems of Policy, Politics and Choice', *Public Administration Review* (July/August 1972), pp. 298-309; and LA PORTE, TODD, 'The Study of Public Organizations', In MARINI, FRANK, *Towards a New Public Administration*, Scranton: Chandler, 1971, p.20.
17. SCOTT, WILLIAM, 'Organizational Government: The Prospects for a Truly Participatory System', *Public Administration Review* (January/February 1969), pp. 43-53; CRAMTON, ROGER, 'The Why, Where, and How of Broadening Public Participation in the Administrative Process', *Georgetown Law Journal* 60:3 (February 1972), p. 529. See also GELLHORN, ERNEST, 'Public Participation in Administrative Proceedings', *The Yale Law Journal* 81:3 (January 1972), p. 367.
18. A review of these problems appears in WADE, NICHOLAS, 'Freedom of Information', *Science* 175, 4 February 1972, pp. 493-502; and KOLATA, G., 'Freedom of Information Act: Problems at the FDA', *Science* 189 (4 July 1975), pp. 32-33.
19. An unpublished report by SULLIVAN, J., cited in BOASBERG, TERSCH, 'Implications of NSF Assistance to Non-Profit Organizations', *Report to NSF*, Washington, D.C. (1977), p. 64.
20. GRAY, BRADFORD, COOKE, ROBERT A., and TANNENBAUM, ARNOLD S., 'Research Involving Human Subjects', *Science* 201:22 (September 1978), pp. 1094-1104.
21. For a review and bibliography on citizen litigation, see DIMENTO, J., 'Citizen Environmental Litigation and Administrative Process', *Duke Law Journal* 22 (1977), pp. 409-452. For the difficulty of finding conceptual correspondence between scientific developments and legal concepts, see CARROLL, JAMES, 'Participatory Technology', *Science* 171 (19 February 1971), pp. 647-653.
22. CLARK, ROGER, and STANKEY, GEORGE, 'Analyzing Public Input to Resource Decisions: Criteria, Principles, and Case Examples of the Codeinvolve System', *Natural Resources Journal* 16 (January 1976), pp. 220-222.
23. MURRAY, B. et al., 'Peaking Plant Environment Report (EAC, September 1973)', reported in HEBERLEIN, THOMAS, 'Some Observations on Alternative Mechanisms for Public Involvement: The Hearing, Public Opinion Poll, the Workshop, and the Quasi-Experiment', *Natural Resources Journal* 16 (January 1976), pp. 197-212.
24. For reviews of environmental mediation efforts, see the EIA Review published at MIT.

25. Cambridge Experimentation Review Board, 'Guidelines for the Use of Recombinant DNA Molecule Technology in the City of Cambridge', December 21, 1976.
26. For an extended review of these models, see NELKIN, DOROTHY, *Technological Decisions and Democracy*, Beverly Hills: SAGE Publications, 1978.
27. See discussion in U.S. Congress, Senate, Committee on Government Operations, *Public Participation in Government Proceedings Act of 1976, Hearings*, Washington, D.C.: GPO, 1976.
28. BAZELON, DAVID L., 'Risk and Responsibility', *Science* 205 (20 July 1979), p. 278.
29. See *Daedalus*, March 1978, devoted to the theme of Limits of Scientific Inquiry, and the Nobel Symposium, Volume 44, *Ethics for Science Policy*, Pergamon Press, 1979.
30. A study of IRBs found that, although accepting the legitimacy of the IRBs, 25% of the 940 biomedical scientists and 38% of the 395 behavioural and social scientists interviewed felt the review procedures are an unwarranted intrusion on the investigator's autonomy; 43% of the biomedical scientists and 54% of the behavioural scientists felt the procedure had impeded the progress of research. National Commission for the Protection of Human Subjects, *Report and Recommendations on Institutional Review Boards*, DHEW Publication (OS) 78-0008 (September 1978), p. 75.

Studies in Science Education 9 (1982), 65-80

Men's Science, Women's Science or Science? Some issues related to the study of girls' science education

CATHERINE A. MANTHORPE
Centre for Studies in Science Education, University of Leeds

INTRODUCTION

It is a well documented fact that, in the Western World, girls and women are significantly under-represented in the physical sciences, both in the education system and within the scientific professions, including science teaching.[1] The following paper draws mainly upon evidence relating to the U.K., but it is believed that the issues raised are relevant to other Western countries.

As long ago as 1869 Lydia Becker posed the question, 'Why do students of science among men greatly outnumber those among women?'.[2] At the time when she was writing, the availability of science education for all could by no means be taken for granted; furthermore, science itself had not yet become a fully professional activity.[3] It is only during the last few decades of the twentieth century that the same question, as evidenced by many publications,[4] has elicited official recognition of a problem and has become an urgent consideration for women.

From the work that has been published, three distinct, though not unrelated, perceptions of the problem are evident. One, which may be called the State or managerial view, sees the intellectual potential of girls as a significant untapped resource for scientific and technological labour power. The second interprets the problem as one of equality of opportunity and seeks to identify and reform those factors believed to be working against the achievement of girls in science. The third view recognizes the incidence of the under-representation of girls and women in science as a comment on the nature of science itself, upon the male-female relation, and believes science, as it is now practised, to be oppressive to women. This perception is not one which entails a rejection of science, merely of a specific form of science. As such, the concern represents something of an organisational and even a methodological challenge to contemporary Western science. Each of these three perceptions will be examined in turn.

THE DEMANDS OF STATE AND INDUSTRY

A statement by Mark Carlisle, Secretary of State for Education and Science in the Conservative administration of 1981, identifies the crux of the State's concern. Speaking in that year he explained that, 'The Government's reasons for wanting to encourage girls (to study subjects such as physics, craft, design, technology and engineering) are not entirely altruistic and to do with their personal development. At the moment there is a huge waste of the nation's resources because a large proportion of our young people are ruling out careers in the productive sectors of our economy'.[5]

Statements of this type can be traced back at least to the 1950s when there was growing concern over the shortage of scientific 'manpower'. Committees from industry, education and science met to discuss the problem, considering primarily the shortage and supply of school science teachers.[6] In one report an extension of the practice of employing married women science graduates as part-time teachers in girls' schools was recommended as a means of easing the situation,[7] but generally both women and men are regarded as potential sources of recruits to full-time employment as scientists. In the 1960s concern turned towards the 'swing from science' in secondary schools and universities, as large numbers of students expressed an academic preference for the arts and social sciences, as opposed to the natural sciences. The recommendations of the Dainton Report[8] were largely directed at correcting this imbalance and ensuring an adequate supply of new practitioners to the existing stock of qualified scientists and technologists.

During the 1950s and 1960s there was a growing realisation of the need for a scientifically literate working population because, it was argued, 'without a knowledge of science and of the wide range of technologies based on science these people would be useless, and the industries would eventually come to a standstill'.[9] Some thirty years later the message from industry reiterates the theme; scientists are required in order for industry to be maintained and for it to be competitive. The potential of women to fill the gaps is now more strongly spelled out as is evidenced, for example, by a statement in 1981 from Lord Weinstock, head of the largest engineering combine in the UK: 'There is no sense in turning our backs on the management and technical capabilities of half the population. If we let competitor countries give more opportunities to women than we do, then we are saddling ourselves with a handicap as well as producing a lot of social frustration'.[10]

The response in the 1960s was the injection of industrial and public funds into school science projects such as the Nuffield Foundation's science teaching schemes and the Schools Council's science projects, in order to improve the uptake of science among the school population as a whole. Today such funds are also being directed to affirmative action schemes designed to improve the uptake by girls of science and technology in schools and colleges. Thus, the Engineering Industry Training Board in 1981 ran courses, 'Insight 81', at several universities for the benefit of girls considering careers in engineering, whilst the Manpower Services

Commission has financed a £23,000 project to help women engineers who wish to return to work after having children. An affirmative action project to improve the science achievement of school girls is being undertaken at Manchester University by Dr. Alison Kelly and Judith Whyte with the aid of a grant from the Social Science Research Council.

It should be added, however, that despite anxieties about economic competition and 'manpower' supply, there has always been a reticence to admit, and even positive denials of the claim, that school is the training ground for scientific occupations. Throughout the recent history of science education its dominant rationale has been that the study of science can develop 'processes of thought and forms of behaviour which are both desirable in themselves and transferable to other situations'.[11] That is, science education is an important component of general education which seeks to develop the intellect.

There is, however, another dimension to official concern about science education. Various reports have focussed attention on the scientific needs of the lay person as well as the future specialist. Thus, the Crowther Report[12] identified three reasons for the scientific education of those who did not intend to become scientists and technologists. The first was to ensure that people understood the impact of science and technology on society, thereby reducing any division in language and thought between scientists and non-scientists. Second, it was argued that 'every citizen should be able to use the fruits of technology and to do so intelligently'.[13] Third, education for adaptability was needed in order to cope with a world in rapid change due to the impact of technology, especially on the structure of occupations. In similar manner, the Dainton Report preceded all 'manpower' concerns with those of the 'potentially harmful' effects on both the individual and society of 'the relative decline in the study of science and technology'. The increasing incursion of science and technology into everyday life meant that 'those who have no scientific understanding are cut off from a great human activity; and may well feel excluded from intercourse with those who have such understanding'.[14]

Arguably, this is a responsible and legitimate concern; it is certainly shared by some feminist approaches to the subject.[15] However, investigations of the content of school science curricula reveal their persistent bias towards the needs of future specialists.[16] Even the recent development of science and society courses can be understood as educational reform which will lead to the acceptance of controversial technology and a belief in the legitimacy of decision-making institutions.[17] In these terms, official concern to increase the number of girls choosing science in school may not only reflect the demand for scientifically trained personnel, but may also be part of the response to the popular anti-science, anti-establishment movements of the last twenty years.[18]

EQUALITY OF OPPORTUNITY

As noted above, the concerns of the Dainton Report are echoed partially in the view that women cannot participate on terms of equality with men in a society undergoing constant change due to the effects of science and technology if they do not have sufficient understanding of science. Such understanding is requisite both for job opportunities and for everyday life, few aspects of which remain untouched by science and technology.

However, the focus of the argument now is upon the male domination of science and upon the structures and processes within school and society which militate against girls' success in science. The desire to improve opportunities carries us much further than the mere provision of more science education for girls. A glance at the position of women in the scientific professions will show that, generally, any increase in opportunities afforded by the innovations of the last two decades has largely meant an increase in opportunities for women to become 'secretaries, clerks, machine tenders and technicians',[19] that is, workers in the lower skilled, lower paid sectors of science. Opportunities have been increased 'because they (i.e. women) represent a balance of productive forces and not because their right to participate equally with men in the progress of knowledge has suddenly been recognized'.[20] Women hold 10% of scientific and technological qualifications, yet less than 2% are managers or practising research technicians.[21] Many enter teaching, but again at the lower paid levels. In 1975, for every 113 men professors of science there was one women.[22] In 1969 the Fellowship of the Royal Society of London consisted of 677 men and 20 women. In the same year, out of 721 officers and committee members of the International Council of Scientific Unions only ten were women; four from France, three from Britain, and one each from the Netherlands, the United States and the USSR.[23]

Thus, the objective is to shift the balance of power within scientific organisations at present controlled almost exclusively by men. The dual means to achieve this are, first, improved scientific literacy among women, and, second, a substantial increase in the number of women becoming professional scientists and technologists.[24]

Over recent years, research has been undertaken in order to determine the reasons for girls' underachievement in science and to guide 'affirmative action' designed to improve their performance. Broadly, the conclusions of such work may be categorised under two headings; 'biological explanations' and 'social explanations'.

Those who propose that biological factors determine girls' underachievement suggest that females are not endowed genetically with skills necessary for successful performance in the physical sciences, notably those skills associated with high analytic and visual-spatial abilities. The argument usually rests on the finding that females show a lesser ability in relation to visual-spatial tasks than do boys.[25] However this argument can be contested as unsound for at least two reasons. First, it cannot be ruled out that this ability is learnt. It has been found that visual-spatial ability is superior in males in adolescence and in adulthood, but not in childhood. In some cultures the sex difference in this ability is minimal or non- existent and evidence has shown that independence from early life can result in high visual-spatial ability in both sexes.[26] Furthermore, if it can be claimed that 'the development of the ability to think analytically is related to the development of the qualities of independence, initiative and assertiveness',[27] then the experience of girls' lives can begin to determine whether or not they have the opportunities to develop such abilities. One possibility is that girls have more sheltered lives than boys and are subject to greater restrictions and closer control. Another possibility, discussed below, is that these qualities in the West are not considered very feminine and thus 'many girls . . . are prevented from trying to do their best, particularly in competitive situations, by the belief that they will be seen as unfeminine'.[28]

The second reason is that the biological explanation is too clear-cut, and does not take into account more than the one factor of biological sex. From the biologistic thinking of Aristotle onwards the belief has been promoted and perpetuated that the biological differences in reproduction between men and women condition all the differences and divisions between them.[29] The visual-spatial 'proof' of women's innate lesser ability in science may be seen as one more in a long series of justifications by biologists for women's subordinate position in society.[30] Finally, in the attempts to discover the reasons for girls' underachievements the biological argument is something of a red herring, for, as Radcliffe-Richards indicates, even if a clear biological component did exist 'feminists can give complete justification for action simply by pointing to the discriminatory pressures which demonstrably exist'.[31] As a strategy in itself, however, the biological explanation can serve to support the view that the position of women in science (and in society) is natural and inevitable and thus nothing can be done about it.

Explanations for girls' underachievement in science which do look to the social sphere suggest a complex of factors in operation. By the triple socializing agents of the family, school and society, girls learn to conform to a stereotype of femininity, a learnt role of such attributes as passivity, dependence and sentimentality. In early schooling girls do achieve more highly than boys in all subjects. By the time they reach adolescence however, the achievement of 'femininity' becomes an overriding factor in their lives. Girls are placed within the contradictory position of having to be 'feminine' which variously means avoiding success; or choosing particular subjects such as the arts, the humanities and the biological ('the soft') sciences; or risking deviation from the social norm in pursuing an intellectual education.[32]

Kelly discusses at length various socialization theories, rightly pointing out that 'it is important to understand how sex typing takes place if we wish to counter it'.[33] Critical of a crude, behaviouristic approach to child rearing (i.e. reward the 'correct' behaviour and punish the 'incorrect') adopted by many feminist accounts of socialization, Kelly favours the cognitive-development approach. In terms of this the child is 'an active participant in structuring her or his experience, and formulating sex-role concepts'; thus 'cognitive theories see the child as essentially self-socializing, first developing categories and then fitting her or himself into these categories'.[34] In contrast, social learning theories see the child as 'essentially passive, being moulded by external forces'.[35] This obviously has implications for reforms aimed at increasing girls' achievement, as will be discussed later (p. 71). First, an outline is given of some of the recent research which has identified the different social factors in operation which act against girls' science achievement.

The literature[35] suggests that there are four sets of processes in operation. First, there is the organisation of the school, including considerations such as the structure of option schemes, timetabling and the availability of certain subjects.[37] Second, there is the influence of teaching approaches and the science curriculum: the subject content of the curriculum which traditionally draws upon skills which boys will be more likely to have acquired in their earlier play than girls;[38] text-books which portray scientists as men, and in which, if women are pictured at all, they appear in domestic and service roles;[39] examination syllabuses and the design of examination questions;[40] the lack of girls' involvement in science lessons because of teachers' attitudes towards them; and the small proportion of physical science teachers who are women, a situation which helps to reinforce the notion that physical science is a subject for boys.[41] Third, parental attitudes and careers advice can have negative and discouraging effects upon girls when they try to opt for subjects which are outside 'traditional' women's areas.[42] Or careers advice may leave girls ignorant of the need for a knowledge of science in future occupations.[43] Finally, and perhaps most importantly, the fourth process is one which involves the pupils' beliefs and attitudes about the subject. Science has a masculine image which significantly shapes the way in which girls and boys perceive it.[44] The stereotypical personality traits for scientists stress impersonality, high ability and detachment,[45] traits which, as noted above, are antithetical to the ideal of femininity. Furthermore, the physical sciences are perceived to lead to traditionally male-oriented qualifications whereas biology, connected with 'people' and 'life', is considered relevant for many traditional women's occupations such as nursing and child rearing.[46] Options to study or not to study science are presented just at a time when girls are forming conceptions about their femininity and it could well be that subject choice reinforces gender identity.[47]

Finding such as these have influenced positive measures in some schools[48] and Kelly has used them as a basis for a long term project in Manchester schools. Cognitive development theories which influence Kelly's work suggest that the elimination of sex differences 'may make children more conformist to those distinctions which they can establish and may even cause them anxiety over gender roles'.[49] The aim, then is 'not towards a neutral or sex free conception of behaviour, but towards reversed or dual sex typing'.[50] Thus Kelly believes that, rather than promoting an androgynous conception of science, strategies should aim 'towards giving science a more feminine image and convincing young girls that achievement in science is a normal and acceptable part of feminine behaviour'.[51] Suggestions for how this may be done begin with 'compensatory science' for girls, filling in background knowledge and attitudes and thus bringing girls to the same starting point as boys.[52] Links could be made in the physical sciences with the traditional feminine concerns of the home, body and community.[53] Examples of physics related activities could easily be incorporated from women's lives, 'air-pressure (vacuum-cleaner), heat transfer (cooking-domestic heating) electric circuitry (domestic wiring) density (shopping), energy change (almost anything)'.[54] Both for girls and boys the distinction between the physical and domestic sciences could be dropped, 'feminising' the subject yet not changing the basic concepts, theories and experimental method of physical science.[55] An addition of more 'home-based' topics could restore the balance of a curriculum distorted by their omission.[56] Working alongside such methods could be more science and mathematics remedial classes, more directive teaching, more balanced text-books, single sex classes and better careers advice.[57] One possible problem resulting from the attempt to 'feminise' the science curriculum may be that the status of the subject will be lowered. Curran has noted that girls more readily take up science and society courses because of their social relevance, but that these courses are often offered as an alternative for less bright students and consequently have lower status connotations.[58] It is also interesting to note that domestic science for much of its history has been seen as an ideal means of imparting scientific knowledge to girls, but such a domestic science has never been incorporated into the main stream of school curricula and generally remains as an option for less academic girls.[59] Kelly does acknowledge this point but insists that 'the aim must be to develop a more humanistic science'.[60]

Kelly's approach seeks to locate, and remove or change, those factors operating particularly within the science curriculum and science teaching which either inhibit girls from choosing the physical sciences or are contributory towards girls' under-achievement. As has been discussed, one of the major factors in operation is the masculine image of science. This image is acquired by the indubitable domination of science by men, which often leads to the conclusion that science is a male discipline. However, Kelly contends that this image is not inevitable or necessary. Citing work by Mitroff, Mahoney and Roe,[61] Kelly indicates that in contrast to the sterotypical image of the scientist as an objective, detached and unemotional person, 'successful scientific activity demands intense commitment to a particular point of view, and gifts of intuition, speculation and risk-taking'.[62] Scientific activity is only deemed a masculine activity because of the lack of women participating. Indeed, although Kelly is aware that it cannot be easy, she argues that it may 'be possible to reverse the process by attacking the masculine connotations of science and so rendering it more attractive to women'.[63]

MALE SCIENCE?

It might be argued against Kelly's approach that the terms of the inquiry, 'to elucidate the origins of girls' underachievement in science and suggest ways to improve their performance',[64] focus attention unduly upon the failure of girls and not upon science. In other words the impression is given that more girls taking the physical sciences is a desirable goal in itself. Although Kelly is not entirely uncritical of science and does acknowledge its prevailing military and industrial biases to the detriment of more humanitarian concerns,[65] there is a tacit adherence to a 'use-abuse' model of science. Such a model implies that there is a correct and an incorrect way of using science and that, in this case, the contemporary distortions and abuses of science mainly stem from its male domination. The practical implications of this for Kelly are that if women are to change science they must do so from the inside and from a position of literacy and fluency in the basic knowledge and skills of science.[66] Steps made towards this position are 'part and parcel of changing women's position in society'.[67]

However, this point of view is strongly contested by other feminist commentators upon women and science. They claim that it is not feasible to compete in the scientific world without conforming to the dominant scientific ethic which, among other things, sees the female 'as passive, weak, irrational, emotional and hopeless'.[68] It argued that women can only enter science upon male terms, as tokens, and nothing is changed.[69] Experiences of women in science tend to show that women are often isolated within the scientific community, are subject to both formal and informal discriminatory procedures and lack adequate facilities whereby they can combine childrearing with their scientific career.[70] In consequence, women scientists are generally unable to reach any positions of influence from which they might begin to change science from within.[71] Furthermore, historical research has shown that some scientific fields are more open to women than others and that the nature of these fields is likely to be determined by the growth-rate of a particular science.[72] Different sciences have different statuses which vary according to their perceived economic and military significance at any particular time;[73] thus not only will the higher status of a science mean the greater exclusion of women from the field, but all other areas in which women might be well represented will be marginalised, trivialised and deemed 'low status'.[74] Of course, the label 'low status' would not matter if it did not have the consequences it does in terms of research funding and access to positions of influence.

Science, its organisation, methods, relationship with, and effects upon, society is thus the focus of inquiry for what has been identified as the third perception of the problem of girls and science education. Whilst the literature is not directed explicitly towards science education, as a critique of science it does have implications for issues such as why girls either choose not to take science or drop out of science at a later stage in their educational or professional careers.

Curran, after considering the biological and social reasons why girls are largely absent from science, suggests a third reason: 'girls don't want to do science partly because they are brought up to think that it is a male subject and partly because it *is* a male subject'.[75] Griffiths suggests that women 'don't want to participate more fully in a science which is patriarchal, hierarchical and authoritarian, and which is used to oppress and exploit the mass of people in the interests of the few'.[76] The implication here is that science is rejected at the level of values with which scientific knowledge and application are seen to be associated. Brief discussion has already been given above (p. 70) of what these values are perceived to be and how they are antithetical to girls' interests. This third view believes that the problem is more fundamental than the operation of a stereotype which alternative text-books and teaching attitudes can effectively counter. Rather, the assumption is that science is a social construct, its development is inextricably linked with social relations, not least the relations between women and men. Thus science in a patriarchal, or male dominated society has in-built features which actively discourage girls and women from studying it.

Such a view is supported by some recent studies in the history of science.[77] These suggest that a changing attitude towards nature both made possible and was in turn affected by the emergence of modern Western science in the 16th and 17th centuries. Furthermore this changing attitude was significant in the development of the value system of modern science. Merchant illustrates how, prior to the 16th century, the world-view was an organic one in which nature was associated with the source of life, with the female and with vitality.[78] There were strong moral and cultural sanctions against the invasion and destruction of nature. Mendelsohn cites those who argue that the Judeo-Christian tradition, by its belief that humans were in God's image and thus were given power over nature, and by the destruction of pagan animism which saw life in all things, 'made it possible to exploit nature in a mood of indifference to the feelings formerly assigned to natural objects'.[79] Thus the path was opened for the emergence of a mechanistic world view which conceived 'nature, society and the human body . . . (as) . . . interchangeable, atomized parts that can be repaired or replaced from the outside'.[80] In other words, a formerly holistic, organic conception of the cosmos became fragmented. Nature was no longer mysterious, nurturative and revered, but 'mere matter' open to investigation and violation. Such a view of nature, as an object to be examined and explained, tended to determine what became legitimate scientific knowledge. Precursors to modern scientists, – alchemists, magicians, metaphysicians and experimentalists – found no place in science of the post English Civil War period. Such a science, in order to survive the re-establishment of the Church as the source of knowledge and authority during the Counter Reformation, confined itself to a strictly empiricist interpretation of the world dealing only with reason and experience. Social and political or normative questions, the subjective and irrational, became outside the field of scientific inquiry.[81] The success of such a narrow conception of science was ensured by the achievements of the Industrial Revolution, achievements which were informed by the findings of scientists and which in turn helped to ensure the increasing power and authority of science.

Merchant has shown that such a specific development of science had crucial implications for women, themselves associated with nature, the subjective and the intuitive. The antithetical view to nature as the provider of nurture and fertility was the image of nature as disorder. As the development of modern science sought the increasing domination of a chaotic natural world so did it sanction the domination of men over 'disorderly female nature'.[82] By the end of the century Europe had seen thousands of women killed in the witchhunts for supposed powers which were perceived to be a threat to a social order in which women were deemed inferior to men.[83] The 'objectivity' of science defended women from accusations of witchcraft, but it did so only by showing that 'because of the fragility of their sex women were heedless in their beliefs, impatient, melancholic and unable to control their emotions'.[84] Also, by this time, women's traditional control over their reproduction was being undermined by the new scientific methods of the male midwife and doctor.[85] Thus the death of nature or rather 'the reconceptualization of reality as a machine rather than a living organism, sanctioned the domination of both nature and women'.[86]

The extent of women's sexuality and the supposed disorder to society which it brought was partially the motivation behind the witchhunts.[87] Easlea, in a view informed by a psycho-analytic approach, takes this male fear of female sexuality as part of the driving force behind the search for causal knowledge, for it enabled 'ruling-class males to display virility by a massive technological appropriation of nature'.[88] He notes that throughout the writings of natural philosophers 'the imagery (is) of male sexual wooing, conquest and penetration of female nature'.[89] The scientific quest was therefore an 'essentially virile, masculine adventure'.[90] Thus, Easlea can believe that from its origins and subsequent development modern Western science is intrinsically a male pursuit and moreover an irrational pursuit because of its oppressive and violent aspects.[91]

There is not scope within this paper to examine such historical explanations of the development of modern science in detail, nor to give a critical assessment of them. However, although sketched only briefly, their explanatory value lies in their conceptualisation of science as 'constituted by and constituting social relations'.[92] Thus it can be understood that, with the development of modern science, increasing social power was given to a view of the world requiring abstraction, analysis, 'objectivity' and control – skills appropriated by men by dint of their socially defined role and developed within an education system open only to the male ruling class. Conversely, the former positive values associated with nature were undermined and relegated to a subordinate position. The same was true for women, who were associated with the irrational and subjective, dispositions which no longer held a place in scientific inquiry. Values of passivity, sentimentality and nurturance were denoted as 'feminine', actively encouraged in women and yet ascribed a lower status and thus less power.[93] Science was able to become a powerful legitimator of a status quo in which men had and have power and control over women.

Recent feminist inquiry into the operations and effects of Western science have begun to show how the 'sanctioned domination of women' continues.[94] Interestingly, the emphasis tends to be upon the biological and medical sciences as these have so often been used to justify women's subordinate position in society. It is almost ironic that these branches of science have the greatest appeal to girls, but, apart from the many reasons why this might be so, it may be said that the connection between, for example, the a-social context of the biology lesson on human reproduction and the most recent developments in the contraceptive pill is very weak. (In other words, the school image of biology bears little relation to the operations of biological and medical science). However, it is in this sense that this third perception of girls and science differs radically from the first two, for in its critical focus upon science *per se,* it goes beyond the 'conventional division of sciences into separate compartments designed by examining bodies'[95] to look at the methods, ethics and values involved in the 'scientific attitude'.

From such a critique an alternative conception of science is beginning to emerge. Drawn from several sources the consensus on an alternative, feminist science would seem to involve at least the following. Firstly, the values traditionally ascribed to women are given a positive and central place; that is emphasis is placed on a re-uniting of the intellect and emotion and there is a revaluation of women's traditional 'sentimentality', women's 'feminine' belief that the quality of life has priority over economics or efficiency or 'rational' planning'.[96] Secondly, scientific activities should reflect a balance with and not an exploitation of nature, with an alteration in research priorities away from means of destruction and 'big business' interests to the needs and benefit of all sections of the community. Thirdly, an alteration of world view is required, from the analytical fragmentation of modern science to a holistic view in which social, ethical and moral considerations are unquestionably involved. Fourth, a scientific community should be based on cooperation, social accountability and accessibility, and not be a closed hierarchical system. Finally, there should be a respect for and equal valuations of different forms of knowledge, including the 'irrational' and the 'subjective'.[97] How such an alternative might emerge is, as some women suggest, 'the chief methodological challenge that confronts the feminist revulsion against the Baconian warrior'.[98]

As yet the critique is only at the stage of being voiced in a disparate collection of articles. Different criticisms emphasize different points and there is no clear aim, or priority of aim, except in the unified condemnation of contemporary science and the belief that women could produce something better. We cannot yet know what a 'woman's science' may be. Spender[99] suggests that because 'women and men are positioned differently in patriarchal order . . . this in itself makes it possible to speak of women and men as inhabiting different worlds which give rise to sexually differentiated meanings and explanations of these worlds'. Thus the implication is that a science developed on women's terms would be substantially different to one developed by men. However, any conception of an alternative science confronts issues in the philosophy and methodology of science. In a sense there are many alternative sciences, but the argument here is implicitly with the positivist/empiricist method, which assumes objectivity, 'pure fact' and scientific 'truth' available for whosoever chooses to use it. A problem with much of the recent writing is that this is not made clear. There is an apparent confusion of aims between, on the one hand, the interests, effects and use of science and, on the other, its methodological assumptions. Thus it is not apparent whether the call is for a radical re-structuring of science or for the appendage of a feminist perspective in science, not dissimilar to Kelly's aims to 'femininize' the school science curriculum. If, however, one conceives science to be constituted by social relations, the attempt to change science, for example by feminist research projects, without changing the social relations upon which it is built leaves untouched the most powerful factor in operation which maintains the *status quo,* that is, the relations of domination and subordination between men and women. A truly alternative feminist science must be almost impossible to imagine for it must be involved with an alteration in the relationship between men and women, and thus with an alternative society and consciousness. As one writer has noted, the possibility of such 'a woman-centred science would be so radically different that it would no longer be invested with the meaning of 'science' as we now understand it'.[100]

Unlike the first and second perceptions of the problem of girls and science this view suggests no clear lines of action. However, it would be misleading to suppose that these particular views imply no change in science teaching in the belief that science is a male sphere. No doubt the contributors to the critique would support most attempts to improve science facilities for girls. What the critique does do, is set those attempts into a wider perspective and show the limitations of 'affirmative action' not only in terms of the broader social pressures in operation against girls, but also in terms of the inherent assumptions of contemporary science. The critique shows that 'equality of opportunity is not enough'[101] and it has begun to make explicit some of the ideals for a change which it seems must occur both within and outside science if the majority of girls and women are going to consider it a worthwhile and valuable subject.

REFERENCES

1. See, for example, KELLY, A., 'Girls and Science. An International Study of Sex Differences'. In: *School Science Achievement.* IEA Monograph Studies No. 9, Almquist and Wiksell, Stockholm, 1978. KELLY, A., 'Girls and Science Education: is there a problem?' In: KELLY, A., (ed.) *The Missing Half – Girls and Science Education*, Manchester University Press, 1981. ROSSI, A., 'Women in Science – Why so few?', *Science* 148 (1968) 1196. COUTURE-CHERKI, M., 'Women in Physics'. In: ROSE H., and ROSE, S., (eds.) *The Radicalisation of Science*, Macmillan, 1976.
2. BECKER, L., 'On the Study of Science by Women', *Contemporary Review*, 10 Jan.-Apr. 1869, 396-404.
3. LAYTON, D., *Science for the People*, Allen & Unwin, London, 1973. CARDWELL, D. S. L., *The organisation of science in England*, 2nd ed., Heinemann, London, 1972. MENDELSOHN, E., 'The emergence of science as a profession in nineteenth-century Europe'. In: HILL, K., (ed.) *The Management of Scientists*, Beacon Press, 1964.
4. For a bibliographic review see KELLY, A., 'Women in science: a bibliographic review', *Durham Research Review* 7 (36) (Spring 1976) 1092-1108. More recent American work is reviewed in: KAHLE, J. B., 'The Disadvantaged Majority: Science Education for Women and Minorities'. Unpublished paper presented to a U.S.A./U.K. Science Education Seminar, London, Jan. 1982. See also ALDRICH, M. L., 'Women in science', *Signs. Journal of Women in Culture and Society*, 4(1) (Autumn 1978) 127-135.
5. Quoted in *Equal Opportunities Commission News* (February/March 1981) 7.
6. See for example: NATIONAL ADVISORY COUNCIL ON THE TRAINING AND SUPPLY OF TEACHERS *Graduate Teachers of Mathematics and Science*, HMSO, 1953. ASSOCIATION OF TEACHERS IN COLLEGES AND DEPARTMENTS OF EDUCATION, *The Supply of Mathematics and Science Teachers*, Methuen, 1956. FEDERATION OF BRITISH INDUSTRIES, *The Shortage of Science Teachers*, Metcalfe and Cooper, 1954. ASSOCIATION OF SCIENTIFIC WORKERS JOINT COMMITTEE FOR SCIENCE AND EDUCATION, *The Supply of Science Teachers in England and Wales*, A. Sc. W., 1962.
7. NATIONAL ADVISORY COUNCIL op. cit. (ref. 6), 10.
8. THE COUNCIL FOR SCIENTIFIC POLICY, *Enquiry into the flow of candidates in Science and Technology into Higher Education*, (Dainton Report) HMSO, 1968.
9. FEDERATION OF BRITISH INDUSTRIES, op. cit. (ref. 6) vii.
10. Quoted in EVERLY, B., *We can do it now – a report on some good practices in science, technology and crafts in schools.* Part 1. (E.O.C. 1981).
11. MILLAR, R. H., Curriculum and Control. The Rhetoric of School Science Curriculum Innovation 1960-1980. M. Phil. Thesis, Edinburgh, 1981.
12. MINISTRY OF EDUCATION, *15-18.* A report of the Central Advisory Council for Education (England), (Crowther Report) HMSO, 1959.
13. Ibid., 51-2.
14. DAINTON REPORT, op. cit. (ref. 8) 1.
15. KELLY, A., (1978) op. cit. (ref. 1) 3. GRIFFITHS, D., 'Women and Science: A woman replies'. In: HINTON, K., (ed.) *Women and Science*, SISCON Project, 1976.
16. MILLAR, op. cit., 9. CURRAN, L., 'Science Education: Did she drop out or was she pushed?' In: Brighton Women and Science Group (ed.), *Alice Through the Microscope.* Virago, 1980, 39.
17. GASKELL, P. J., 'Science, Technology and Society: Issues for Science Teachers', *Studies in Science Education*, 9 (1982), 35. For reviews of the ASE, Science in Society course see: PREECE, P., 'Uneven Course', *The Guardian*, 24.3.81. LANCASTER-GAYE, R., MATTHEWS, R., and ROWE, F., 'Used or Abused?', *The Times Educational Supplement*, 13.3.81.
18. COTGROVE, S., 'Objections to Science', *Nature*, 250 (1977) 764-767.
19. ROSSI, A., 'Women in Science – Why so few?' op. cit. (ref. 1).
20. STÉHELIN, L., 'Sciences, Women and Idealogy', In: ROSE & ROSE (1976) op. cit. (ref. 1) 78. See also in this respect BLAKE, J., 'The Changing Status of Women in Developed Countries, *Scientific American*, 231 (1974) 137.

BEST COPY AVAILABLE

21. Cited in CURRAN, L., op. cit. (ref. 16) 23. For the position of women in British Astronomy see MARTIN, BEN R., and IRVINE, JOHN 'Women in Science – the Astronomical Brain Drain', *Women's Studies International Forum*, 5(1) (1982) 41-68.
22. Statistics of Education, HMSO, 1975.
23. LONSDALE, K., 'Women in Science: Reminiscences and Reflections, *Impact of Science on Society*, 20 (1970) 45-59.
24. KELLY, A., (1978) op. cit. (ref. 1) 3.
25. See, for example: GRAY, J.A., 'A biological basis for sex differences in achievement in science'. In: KELLY, A., (ed.), *The Missing Half – Girls and Science Education*. op. cit. (ref. 1). For a review of biological sex differences see: LAMBERT, H. H., 'Biology and Equality: A Perspective on Sex Differences', *Signs*. op. cit. (ref. 4). For a review of research on spatial ability see: ELIOT, J., and HAUPTMAN, A., 'Different Dimensions of Spatial Ability', *Studies in Science Education*, 8 (1981) 45-66. Nafferton Books.
26. MACCOBY, E. E., and JACKLIN, C. N., *The Psychology of Sex Differences*, Stanford University Press, 1975.
27. MACCOBY, E. E., 'Feminine Intellect and the Demands of Science', *Impact of Science on Society*, 20 (1970) 13-28.
28. Ibid.
29. HOROWITZ, M. C., 'Aristotle and Woman', *Journal of the History of Biology*, 9(1), (Spring 1976) 183-213.
30. MOSEDALE, S. S., 'Science Corrupted – Victorian Biologists Consider "The Woman Question"', *J. of the Hist. of Biol.* 11(1) (1978) 1-55.
31. RADCLIFFE-RICHARDS, J., *The Guardian*, 30.1.81.
32. The literature on this is quite extensive. See for example: SPENDER, D., and SARAH, E., (eds.), *Learning to lose – Sexism in Education*, Women's Press, 1980. DEEM, R., *Women and Schooling*, Routledge Kegan Paul, 1978. DEEM, R., (ed.), *Schooling for Women's Work*. Routledge Kegan Paul, 1980. SHARPE, S. *Just Like a Girl – How Girls Learn to be women*, Penguin, 1976. KELLY, E., 'Socialisation in a patriarchial society'. In: KELLY, A., (ed.) (1981) op. cit. (ref. 1).
33. KELLY, A., 'Science Achievement as an Aspect of Sex Roles'. In: KELLY, A., (ed.) (1981) op. cit. (ref. 1) 81.
34. Ibid. 74.
35. Ibid.
36. KELLY, A., (ed.), *The Missing Half*, op. cit. (ref. 1) is the most recent and accessible collection of research findings.
37. KELLY, A., 'Retrieving the Missing Half'. In: KELLY, A., (ed.) (1981) op. cit. (ref. 1). DEPT. OF EDUCATION AND SCIENCE. *Curricula Differences for Boys and Girls*, HMSO, 1975.

3. KELLY, A., 'Retrieving The Missing Half' op. cit. (ref. 1) 277. SAMUEL, J., 'Feminism and Science Teaching: Some Classroom Observations'. In: KELLY, A., (ed.) (1981) op. cit. (ref. 1) 248.

39. WALFORD, G., 'Sex bias in physics text-books', *The School Science Review*, 62(219) (Dec. 1980) 220-227.
40. HARDING, J., 'Sex Differences in Science Examinations'. In: KELLY, A., (ed.) (1981) op. cit. (ref. 1).
41. HMI Series. Matters for discussion. *Girls and Science*, HMSO, 1980, 18-19. KELLY, A., (ed.) (1981) op. cit., chapters 17, 18, 19.
42. HMI Series. *Girls and Science*, op. cit. 10-11.
43. NEWTON, P., 'Who says Girls can't be Engineers?' In: KELLY, A., (ed.) (1981) op. cit. (ref. 1).
44. SMITHERS, A., and COLLINGS, J., 'Girls Studying Science in The Sixth Form'. In: KELLY, A., (ed.) (1981) op. cit. (ref. 1). EBBUT, D., 'Science Options in a Girls' Grammar School'. In: KELLY, A., (ed.) (1981) op. cit.
45. HILLS, P., and SHALLIS, M., 'Images of Science', *New Society*, 28, August 1975.
46. HMI Series, *Girls and Science*, (ref. 41) 9 and 21.

BEST COPY AVAILABLE

47. ORMEROD, M. B., 'Factors Differentially Affecting the Science Subject Preferences, Choices and Attitudes of Girls and Boys'. In: KELLY, A., (ed.) (1981) op. cit. (ref. 1).
48. EVERLY, B., *We Can Do It Now*, op. cit. (ref. 10).

49-51.
KELLY, A., 'Science Achievement As An Aspect of Sex Roles', op. cit. (ref. 33) 81.

52. KELLY, A., (1978) op. cit. (ref. 1) 113: 'Retrieving the Missing Half' op. cit. (ref. 37) 277.
53. KELLY, A., (1978) op. cit. (ref. 1) 113.
54. KELLY, A., 'Women in physics and physics education'. In: LEWIS, J., (ed.) *New Trends in Physics Teaching*, Vol. 3, UNESCO, 1976, 252.
55. KELLY, A., 'Retrieving the Missing Half', op. cit. (ref. 37) 284-5.
56. KELLY, A., (1978) op. cit. (ref. 1) 113.
57. KELLY, A., 'Retrieving the Missing Half', op. cit. (ref. 37).
58. CURRAN, L., op. cit. (ref. 16), 38.
59. See for example: SMITHELLS, A., 'School Training for the Home Duties of women', *British Association for the Advancement of Science. Report* (1906) 781-784. SILLITOE, H., *The History of the Teaching of Domestic Subjects*, Methuen, 1933.
60. KELLY, A., 'Science is for Girls?' *Women's Studies International Quarterly* 2, 291, (1979).
61. MITROFF, I. I., *The Subjective Side of Science*, Elsevier Scientific Publishing, 1974. MAHONEY, M. J., *The Scientist as Subject: the Psychological Imperative*, Ballinger, 1976. ROE, A., 'The Psychology of the Scientist' *Science* 134 (1961) 456.
62. KELLY, A., 'Science is for girls?' op. cit. (ref. 60), 290.
63. KELLY, A., 'Retrieving the missing half', op. cit. (ref. 37) 298.
64. KELLY, A., 'Girls and science education: is there a problem?' In: KELLY, A., (ed.) (1981) op. cit. (ref. 1) 1.
65. KELLY, A., (1978) op. cit. (ref. 1) 113.
66. KELLY, A., (1978) op. cit. (ref. 1) 115.
67. KELLY, A., 'Retrieving the Missing Half' op. cit. (ref. 37) (1981) 295.
68. OVERFIELD, K., 'Dirty Fingers, Grime and Slag Heaps: Purity and the Scientific Ethic'. In: SPENDER, D., (ed.) *Men's Studies Modified: The Impact of Feminism on the Academic Disciplines*, Pergamon Press (1981) 246.
69. For the statement of this point see: FELDMAN, J., 'The Savant and the Midwife'. *Impact of Science on Society*, 25(2) (Apr.–June 1975) 132. OVERFIELD, K., op. cit. (ref. 68) 243. HUBBARD, R., HENIFIN, M. S., and FRIED, B., (eds.) *Women look at Biology looking at Women*, Sheukman Publishing Co. (1979) 207. GRIFFITHS, D., 'Women and Science: A woman replies', op. cit. (ref. 15) 63.
70. SAYRE, A., *Rosalind Franklin and D.N.A.*, W. W. Norton & Co. New York 1975. WEISSTEIN, N., Adventures of a Woman in Science', In: HUBBARD, HENIFIN & FRIED. op. cit. (ref. 69) 187-201. GROTE, J., 'Why a Woman left Science', *New Scientist*, 77, (Jan. 26 1978) 222-3. COUTURE-CHERKI, M., op. cit. (ref. 1). *Science for People*, Women's Collective Issue No. 29, British Society for Social Responsibility in Science, 1975. ROSSITER, M., 'Fair Enough?' *Isis*, 72(261) (March 1981) 99-103. GRIFFITHS, D., op. cit. (ref. 15) 61.
71. The phenomenon of women's caucuses in science may be an attempt to mitigate some of these problems, See: BRISCOE, A. M., 'Phenomenon of the Seventies. The Women's Caucuses', *Signs*. op. cit. (ref. 4) 152-158. 'Women in Computing', *E.O.C. News* (Oct/Nov. 1981).
72. ROSSITER, M., 'Sexual Segregation in the Sciences: Some Data and a Model', *Signs*. op. cit. (ref. 4) 146-151.
73. SARAGA, E., and GRIFFITHS, D., 'Biological Inevitabilities or Political Choices'. In: KELLY, A., (ed.) *The Missing Half*. op. cit. (ref. 1) 93.
74. For evidence of this see: ROSSITER, M., '"Women's Work" in Science, 1980-1910', *Isis*, 71(258) (1980) 381-398. ROSSITER, M., 'Women Scientists in America Before 1920'. In: TRESCOTT, M. M., (ed.) *Dynamos and Virgins Revisited*, Scarecrow Press Inc., (1979) 120-140.

BEST COPY AVAILABLE

75. CURRAN, L., op. cit., (ref. 16) 37.
76. GRIFFITHS, D., op. cit. (ref. 15) 63.
77. MERCHANT, C. M., *The Death of Nature – Women, Ecology and the Scientific Revolution,* Harper & Row, 1980. MENDELSOHN, E., 'Values and Science: A Critical Reassessment', *The Science Teacher* 43(10 (Jan. 1976). EASLEA, B., *Science and Sexual Oppression – Patriarchy's Confrontation with Women and Nature,* Wiedenfield and Nicholson, 1981.
78. MERCHANT, C. M., op. cit. (ref. 77) Ch.I 'Nature as Female'. 1-41.
79. MENDELSOHN, E., op. cit (ref. 77).
80. MERCHANT, C. M., op. cit. (ref. 77) 193.
81. MENDELSOHN, E., op. cit. (ref. 77).
82. MERCHANT, C. M., op. cit. (ref. 77) 127:149.
83. Ibid. 138.
84. Ibid. 141, and EASLEA, B., op. cit. (ref. 77).
85. MERCHANT, C., op. cit. (ref. 77) 151-155. EHRENREICH, B., and ENGLISH, D., *For her own good.*
86. MERCHANT, C., op. cit. (ref. 77) xvii.
87. Ibid. 132-140.
88. EASLEA, B., op. cit. (ref. 77) 82.
89. Ibid. 85.
90. Ibid.
91. Ibid. 2.
92. SHEPPARD, J., Review of *Alice through the Microscope* (unpublished paper).
93. For examples of how this ideology was pervasive in 19th century England see VICINUS, M., (ed.) *Suffer and Be Still – Women in the Victorian Age,* Indiana University Press, 1973. BURSTYN, J., *Victorian Education and the Ideal of Womanhood,* Croom Helm, 1979.
94. See Brighton Women and Science Collective (ed.), *Alice Through the Microscope.* op. cit. (ref. 16). HUBBARD, R., HENIFIN, M. S., and FRIED, B., (eds.) *Women Look at Biology Looking at Women,* op. cit. (ref. 69). DUELLI-KLEIN, R., and MINDEN, S., 'Feminists in science speak up', *Women's Studies International Quarterly,* 4(2) (1981) 241-252. 'Women, Science and Society', *Signs – Journal of Women in Culture and Society,* 4(1) (Autumn 1978). EHRENREICH, B., and ENGLISH, D., *For her own good.* op. cit. (ref. 85). ROSE, H., and HANMER, J., 'Womens Liberation: Reproduction and the Technological Fix'. In: ROSE, H., and ROSE, S., (eds.) *The Political Economy of Science,* Macmillan, 1976.
95. GREGORY, SIR R., 'Educational and School Science', Presidential Address to the Educational Science Section of the British Association for the Advancement of Science 1922. B.A. *Report,* London, 1923, 215.
96. FELDMAN, J., op. cit. (ref. 69) 133. WALLSGROVE, R., 'The Masculine Face of Science', Brighton Women and Science Collective. op. cit. (ref. 16) 233.
97. For such views see: CURRAN, L., op. cit. (ref. 16), 39. WALLSGROVE, R., op. cit. (ref. 96). FELDMAN, J., op. cit. (ref. 69). HUBBARD, R., HENIFIN, M. S., and FRIED, B., op. cit. (ref. 94) Epilogue. OVERFIELD, K., op. cit. (ref. 68), 246-247. FAUSTUS-STERLING, A., 'Women and Science', *Women's Studies International Quarterly,* 4(1) 41-50. ARDITTI, R., *Science and Liberation,* South End Press, Boston. 1970. 365. STEHELIN, L., op. cit. (ref. 20) 89.
98. HUBBARD, R., HENIFIN, M. S., and FRIED, B., op. cit. (ref. 94) 209.
99. SPENDER, D., *Man-Made Language,* Routledge & Kegan Paul, 1980. 77-8.
100. Editorial note to OVERFIELD, K., op. cit. (ref. 68) 237.
101. CURRAN, L., op. cit. (ref. 16) 39.

BEST COPY AVAILABLE

Studies in Science Education 9 (1982), 81-108

Girls and Mathematics and Science. An annotated bibliography of British Work (1970-1981)

DONNA M. KAMINSKI
Sociology Department, Indiana University at South Bend, U.S.A.

Women make up less than 10% of the scientists (including mathematicians, engineers and computer specialists) in the U.K. Why? Are females in general not born with the necessary intellectual capabilities? Today few researchers or educators would attribute much of the imbalance to innate factors. Rather, the interaction of social, cultural, psychological and educational factors seems to be the cause. These factors influence the number of women scientists in two important ways. Firstly, women are less likely to work outside the home – but this is especially true for jobs which are career-orientated, high status areas and 'male' fields (e.g. due to early socialisation, societal definitions of sex roles, culturally prescribed family and work structures and their resultant demands, lack of training and discrimination). Secondly, women are less likely than men to have science training. It is this second area on which the work here focuses.

The Rising Interest in Women and Science

Sex differences in science education have only recently become an area of widespread concern in Britain. Few articles or studies focused specifically on this until the mid-70's. The Girls and Science Education conference at Chelsea College in 1975 (perhaps with the help of the 1975 Sex Discrimination Act) brought particular attention to the issue. Kelly's (1976) subsequent survey of work in the field (drawing from American and Australian literature as well) was an important contribution. Ormerod has also written extensively on the topic, including a book (1975) which surveys research on science attitudes. In 1980 the Department of Education and Science published a major study on girls and science demonstrating government concern with the problem. (Some have questioned, however, whether public concern for girls' under-achievement and under-representation in the physical sciences is motivated more by the 'equality for women' issue or the 'shortage of scientific/technical manpower' issue, e.g. the severe shortage of secondary school mathematics, physics and chemistry teachers). And in 1981 Kelly came out with the first book devoted solely to the topic – an excellent collection of theoretical and empirical articles.

The American Situation

This surge of interest in Britain was predated by American interest which became widespread in the early 1970's. Two important articles discussing the shortage of women scientists by Rossi (1965) and White (1970) came to be widely quoted and reprinted. Sells (1973) and later Ernest (1976) called attention to mathematics as a critical filter in achieving sex equality. The topic of sex differences in mathematics and science became popular for thesis and dissertation research (Kaminski, 1975, 1978), workshops and clinics (Tobias, 1978), the development of mathematics attitude scales (Sherman & Fennema, 1977), government funding of intervention programmes (National Science Foundation, National Institute of Education), government sponsored 'state-of-the-field' literature reviews (Fox, 1976, on socio-cultural factors; Fennema, 1976, on affective and cognitive factors; Sherman, 1976, on biological factors), bibliographies (Chinn, 1980; Aldrich & Hall, 1980), an extensive review of projects/programmes (Aldrich & Hall, 1980, for the American Association for the Advancement of Science) and a number of recent books by leaders in the field (Fox, et. al., 1981; Tobias, 1978; Brush, 1980). Concern soon expanded beyond sex differences in performance to include the perhaps more critical factor of differences in course-taking.

Is American research relevant in Britain?

While there is considerable research in the U.S. on the general topic, much of which is generalizable and suggestive to the British situation, a number of cultural differences in the two education systems suggests that the American findings cannot be transferred wholesale. Britain has more 'open education' in primary schools, many more single-sex and ability/class based secondary schools, a lower school leaving age, credentialing based on elective 16+ individual subject examinations, more compulsory mathematics, a different structure for choice of science subjects, a more select higher education population with lower student/teacher ratios, different teaching methods and shorter degree programmes. Minor differences in sex role definitions, the labour force, traditions and sex-typing of fields also confound the generalizability.

Unlike Britain, the main focus in the U.S. was on sex differences in mathematics as opposed to science per se. This is no doubt due to cultural differences in course options, compulsory subjects and actual sex differences in various areas. Women's deficiency in mathematics was seen as a more general focus of concern beyond its vocational implications for careers in science. For example, mathematics skills and credentials are required for testing and screening (e.g. for entry to university, even in non-science graduate school programmes, and in civil service and other jobs), for the statistics requirements in areas other than natural sciences (e.g. business, sociology, psychology, education), and the increasing computerisation of the world.

Why Don't Girls Take Science?

There is a need for much more empirical work in Britain as to why females are under-represented in science training. Much of what has been written on this subject is merely speculative or does not adequately link presumed causal variables to girls' under-achievement or under-representation in science. We need to investigate (as Curran suggests) whether it is because females 1) can't do science, 2) aren't allowed to (even covertly), or 3) don't want to. The issue is compounded by the fact that actually more girls than boys take biology up to A-levels (where they are about equal to boys). So at the early levels, girls' under-representation is in physics (4:1 at O-level, 8:1 for CSE) and chemistry (2:1). The paucity of women biologists thus goes back to the more general of the two explanations noted initially – i.e. women are less likely to have careers outside the home or to go into male-dominated fields (e.g. many girls take biology to become nurses or biology teachers).

The articles reviewed here provide many promising areas for further investigation (and indeed where work is being done) e.g. teaching/learning styles, biased testing modes, the benefit of all-girl classes, the gender-labelling of subjects, perceptions of subject difficulty, the social implications of science, the masculine and negative image of science/scientists, girls' lack of mathematics skills, and biology as a compromise for science-minded girls. A wide variety of data and methods have been used for research including discussions with students and teachers, classroom observation, a case study of successful schools, analysis of available O-level data, structured questionnaires to measure attitudes, and experiments with different class structures (e.g. all girls classes). Hopefully such an array will continue.

Most research included here focuses on secondary school students, particularly at the initial point of science subject choice (generally 3rd year) and at the time of O-level examination subject choice. While these are certainly critical points in science 'career' development, are there additional earlier factors which set students up for these sex-differentiated subject choices? (Science career interest is found to begin much earlier than other subject areas). Might intervention efforts be effective earlier on? Other critical points such as the decisions for/against 6th form and university entry as well as subject choice at these points also need additional research.

There is also little attention to racial/ethnic and class variations. (One study suggests that females are superior to males for West Indian populations). Most work is also based on English populations. Is the situation the same in Wales, Scotland and Northern Ireland?

This Bibliography

This bibliography is intended to help the researcher quickly review the literature on the topic, being able to select easily those articles she or he wants to examine in greater detail. It is also intended to help science educators, guidance counsellors and administrators who wish to familiarize themselves with the topic and implement changes in their own schools/classes using suggestions and guidelines provided here to develop their own programmes and intervention strategies. Teacher education institutions may find it useful in training science teachers to sensitize them to the problem and its possible causes. And libraries may find it a useful reference tool.

The 62 entries are written in enough detail to avoid having to locate each article, especially difficult for those without easy access to academic libraries with extensive education collections. No doubt some studies which measured sex differences/similarities in mathematics and science have been missed. Prior to the mid-70's, this was generally not seen as an area of pressing concern or central academic interest. And though the variable 'sex' was commonly used in data gathering and analysis, it was not included in the title nor list of key words for indexing as it was only a passing concern of the study. The British Education Index was the guiding source, and references from the articles listed there were followed through as well. The search began with the 1970 literature (up to mid-1981); little was found from the early part of the decade, hence pre-1970 volumes were not examined. (See Kelly's 1976 review for pre-1970 studies).

REFERENCES (British references are included in the bibliography itself. The following are sources from the USA).

ALDRICH, MICHELE L. and PAULA QUICK HALL (1980) *Programs in Science, Mathematics and Engineering for Women in the United States, 1966–1978*, Washington, D.C.: Am. Assoc. for the Adv. of Science.

BRUSH, LORELEI (1980) *Encouraging Girls in Mathematics*, Cambridge: Abt Books.

CHINN, PHYLLIS ZWEIG (1980) *Women in Science and Mathematics Bibliography*, Arcata, Cal.: Math Dept., Humbold State Univ.

ERNEST, JOHN (1976) *Mathematics and Sex*, Santa Barbara: Math Dept., Univ. of California.

FENNEMA, ELIZABETH (1976) *Influences of Selected Cognitive, Affective and Educational Variables on Sex-Related Differences in Mathematics Learning and Studying*, Washington, D.C.: Nat. Inst. of Educ.

FOX, LYNN (1976) *The Effects of Sex Role Socialization on Mathematics Participant Achievement*, Washington, D.C.: Nat. Inst. of Educ.

FOX, LYNN, LINDA BRODY and DIANNE TOBIN (ed) (1981) *Women and the Mathematical Mystique*, Baltimore: John Hopkins Univ. Press.

KAMINSKI, DONNA (1975) 'The Effects of Perceived Parental Evaluations on Skills Development in Mathematics', Kalamazoo, Mich.: MA thesis, Western Michigan Univ.

KAMINSKI, DONNA (1978) 'Entry into Science: The Effect of Parental Evaluations on Sons and Daughters', Kalamazoo, Mich.: PhD dissertation, Western Michigan Univ.

ROSSI, ALICE (1965) 'Women in Science: Why So Few?' *Science* 148, p. 1196-1208.

SELLS, LUCY (1973) 'High School Mathematics as a Critical Filter in the Job Market', ERIC, ED 081051.

SHERMAN, JULIA (1976) *Effects of Biological Factors on Sex-Related Differences in Mathematics Achievement*, Washington, D.C.: Nat. Inst. of Educ.

TOBIAS, SHEILA (1978) *Overcoming Math Anxiety*, New York: Norton.

TOBIN, DIANNE, LINDA BRODY and LYNN H. FOX (1976) *The Effects of Sex Role Socialization on Mathematics Participation and Achievement – Annotations*, Washington, D.C.: Nat. Inst. of Educ.

WHITE, MARTHA S. (1970) 'Women in the Professions: Psychological and Social Barriers to Women in Science', *Science* 170, p. 413-416.

BIBLIOGRAPHY

1. BLACKSTONE, TESSA, and WEINREICH-HASTE, HELEN (1980) 'Why Are There So Few Women Scientists and Engineers?', *New Society* 51:907, 21 Feb., p. 383-385.

The article briefly reviews the general topic. With respect to general educational impediments, girls set their sights lower, take easier courses in further education, take fewer A-levels for higher education and are less likely to go on to higher education (of the 1974–75 school leavers headed for degree courses only 1/3 were female). Psychological factors also hinder girls' later academic success – girls tend to attribute their success to luck and external factors, but attribute their failure to lack of ability – boys tend to be the opposite. This results in patterns of helplessness, avoidance of challenges and lack of self-confidence in girls – factors particularly antithetical to learning subjects perceived as difficult such as maths/science.

Girls are much less likely than boys to take A-level maths (15% vs. 41%) or physics (9% vs. 41%), and instead are more likely than boys to take biology (21% vs. 16%) or English literature (53% vs. 23%). These traditional sex role patterns of subject choice are polarized in mixed-sex schools as compared with single-sex schools (i.e. in mixed-sex schools boys are even more likely and girls even less likely to take maths/physics, while the reverse is true for literature). This sex difference in maths/physics is attributed to factors such as perception of the subjects as masculine (hard, intellectual, complex and concerned with things not people), lack of role models (textbooks, parents, school structure), and teacher expectations. It is suggested that the forced choice between science and the arts be removed.

2. BRADLEY, J. (1981) 'Predicting Specialisation in Science', in A. Kelly (ed) *The Missing Half*, p. 150-163.

This longitudinal study compared 1925 science and non-science students from 15 mixed-sex schools at 2 important decision points with respect to science subject choice – 3rd and 5th forms. It was found that science students had an early and enduring interest in science and that few students reversed their decision once opting out of science in the 3rd form. As to intelligence, science girls scored higher than arts girls, with boys and girls in science doing about equally well. On personality variables, science and arts girls differed much more than the 2 male groups did, with increasing polarisation with age only for girls. Science girls showed close correspondence with the stereotypic scientist personality (emotionally stable, dominant, conscientious, individualistic, confident) with self-sufficiency being the characteristic which most distinguished the science girls from both the arts girls and the science boys.

The high intelligence and personality profile of girls taking science suggests why they were undeterred by social pressures toward sex role conformity. But many students – especially girls – with early science interests opt out in the middle school years, suggesting the importance of early intervention strategies to counteract science's masculine image and the social pressures deterring capable students from science entry.

3. CLEMENTS, M. A. (1979) 'Sex Differences in Mathematics Performance – An Historical Perspective', *Educational Studies in Mathematics* 10, p.305-322.

The author presents a brief look at girls' under-representation in mathematics in recent history in Britain. Until 1862 women were not allowed to sit Cambridge local exams – prior to that girls were rarely exposed to any maths beyond simple arithmetic. In 1912 four papers commemorating the 50th anniversary of admitting women commented on why girls were still not involved in mathematics and should not be. For example, it was too difficult a subject for girls, low expectations, uninteresting, little untilitarian value, wrong presentation of topics in texts, the strains of mathematics study were out of proportion to its gains, and few girls' secondary school teachers were trained in mathematics.

4. CORNELIUS, M.L. and COCKBURN, D. (1978) 'Influences on Pupil Performance', *Educational Research* 21:1, Nov., p. 48-53.

The 1976 O-level performances of 1152 students in one district were examined. The average grade of boys was significantly better than that of the girls in the math/science subjects (e.g. 2.77 vs. 2.34 for those taking the math exam.) as well as in history and geography. Girls were superior in English, religion, languages and commercial subjects. There was no difference for art and music.

5. CURRAN, LIBBY (1980) 'Science Education: Did She Drop Out Or Was She Pushed?' in L. Birke et. al. (ed) (Brighton Women and Science Group) *Alice Through the Microscope: The Power of Science over Women's Lives*, London: Virago, p. 22-41.

After documenting the under-representation of women in the physical sciences (which increases at each level), the article explores 3 possible reasons why – 1) they can't, 2) they aren't allowed to, and/or 3) they don't want to. Firstly, there's the biological explanation – a popular view among the general public as well as a small number of researchers. Yet the 'innate sex difference in spatial ability' argument ignores many factors. Is there adequate empirical evidence? Is it necessarily innate? Is it an integral part of science? Can this single variable explain much variance in science ability/achievement? Is ability a main/sole predictor of achievement? Would evidence for this argument be used for positive discrimination towards girls or merely justifying the current situation?

Secondly, girls don't take science because they aren't allowed to – but today this is generally more covert than overt. Certainly some differences still exist between girls' and boys' schools' course offerings/facilities/resources; and mixed-sex schools offer different options/packages to different students. However, girls are generally 'pushed out' by more subtle discrimination while still appearing to have free choice. Girls learn early that science is a boys' subject (e.g. sex-typing of toys/activities) resulting in girls having less science/mechanical experience. Positive discrimination which favours boys is often not seen as such (e.g. lower 11+ pass marks for grammar school entry), and boys' poorer performance is more likely to be seen as temporary and/or attributable to non-ability factors (e.g. laziness or late development as opposed to innate inadequacy). At the secondary level, pre-emptive patterns in the curriculum along with premature specialisation encourages students to close off future course options at a relatively early age. Girls later face further obstacles at university entry (e.g. less desirable A-levels), gaining technical apprenticeships (lacking earlier appropriate practical experience), and applying for jobs in general (e.g. dual role demands, lack of child care facilities and part time work).

Thirdly, girls don't take science because they don't want to – but the Western cultures socialise them to 'not want to'. Science is seen as a male subject. Girls are constrained by images of femininity which don't value abstract thinking, self-confidence, high intelligence, or independence important for science. Being in the minority (as a woman scientist would be) also has many negative aspects (e.g. informal/social exclusion, assumptions of incompetence, must push harder to be heard). Furthermore, the image of science appears negative to many girls – impersonal, abstract, inhuman, misused, divorced from the social context, and attempting to control, subdue and exploit.

6. DEPARTMENT OF EDUCATION AND SCIENCE (1980) *Girls and Science*, HMI Series: Matters for Discussion 13, London: HMSO.

Three-day visits were made to 15 co-ed comprehensive schools with higher than average ratios of girls to boys on physical science courses. Several science specialists carried out informal observations and discussions with students and staff. There was considerable variability among schools with school differences actually greater than sex differences. The girls in some schools did better than the boys in others in terms of performance and proportion taking science.

The following factors were seen to help/hinder girls' entry into physical science. The negative aspects suggest other strategic changes which should be made. Positive environmental influences included the impact of local science-related industry on parents (many had science qualifications, saw the value of science, held higher expectations) and on the girls themselves (models, information and impression of science), and the general support of a critical mass of girls in science. Career guidance efforts began early, involved parents, discussed available career opportunities, their requirements and how students preliminary subject choices fit, had in-service teacher programmes on the topic, and had specific materials/programmes on females and science, (outside speakers, focused teacher/student discussions). On the negative side, science was seen as masculine, not useful, difficult and limiting on their other subject choices. Girls lacked confidence in their ability and potential, and took physics/chemistry because of career relevance or ability, not pleasure.

As far as actual class factors, girls liked practical work (but lacked experience and confidence in it), were more detailed and attentive to writing assignments than boys without necessarily liking it more), found security in textbooks (but they rarely showed aspects girls found relevant, e.g. social implications, practical relevance and human involvement). On the other hand, girls were reluctant to participate in discussions (not called on by teachers, feared wrong answers and mocking from boys), had difficulty understanding science (lacked confidence even if they had the ability, lacked math skills) and didn't think science was relevant (to themselves, people, everyday life or girls' experiences).

Successful science programmes used more concrete examples and domestic applications, and showed practical aspects of science to everyday life. Science in later years necessarily becomes more abstract to prepare for O-level exams, but this change from interest-based to exam-based should be gradual. Perhaps exam boards should re-examine syllabi and incorporate more young people's (and girls') concerns. (Physical science should be seen as general education and not solely in vocational terms). Science teachers in the early years should be especially well-qualified and experienced (i.e. before student decision time), sympathetic (taking time to explain), try to actively involve girls, be involved in extra activities and have industrial experience and/or knowledge of industrial opportunities in science.

7. DEPARTMENT OF EDUCATION AND SCIENCE (1980) *Mathematical Development*, London: HSMO.

A national (England, Wales and Northern Ireland) representative sample of 14,000 15 year olds from nearly 600 schools was tested by the Assessment of Performance Unit. Fifteen skills were tested in the areas of numbers, measures, algebra, geometry and probability/statistics – these were examined for their relationship to 5 school characteristics and the variable sex.

Boys had higher scores in all 15 subcategories – the sex difference was significant in 11. Boys' score averaged 3.5% higher than girls. Boys were furthest ahead in geometry (7%) and 2 measurement subcategories. Boys were considerably more likely to score in the high performance band than girls (2:1 for the top 10%), while there was virtually no difference between the proportions of boys and girls in the lowest band.

A comparison of these results with a separate national survey of 11 year olds, showed an increasing sex difference with age. Earlier on, boys scored higher than girls on 10 of 13 sub-categories (1-2% differences only) while girls were ahead in 3 categories of computation (4% ahead).

8. DOBSON, CLIFFORD B. (1979) 'Study Inventory Responses and 'A' Level Grades', *Educational Studies* 5:2, June, p. 127-134.

Arts and science students were compared as to whether study habits (i.e. delay, avoidance and work methods) and study attitudes (i.e. teachers' approval and educational acceptance) were related to A-level achievement (better grades). High correlations between each scale and performance were found for the 290 6th form students (grammar and comprehensive). For science students, study attitudes were better predictors of performances, for arts students study habits were better predictors.

All 4 study orientations were strongly associated with achievement for females but had little overall relationship for males (except work methods). Educational acceptance was the most important for females in general. Teacher approval was particularly important for female science students.

9. DOE, BOB (1980) 'Winners and Losers in the Numbers Game', *Times Educational Supplement* 3321, 1 Feb., p. 6-7.

In 1978 13,000 11 year olds from 1,000 schools took the Government Assessment of Performance Unit test in maths. Boys' performance was slightly superior to girls' in all categories except computation with whole numbers and decimals where girls were markedly better.

10. DRIVER, GEOFFREY (1980) 'How West Indians Do Better at School (Especially the Girls)', *New Society* 51:902, 17 Jan., p. 111-114.

This study looked at the 16+ exam results of 2300 intercity school leavers from 5 multiracial schools. Girls and boys from West Indian, Asian and English backgrounds were compared on achievement in maths, science and English language. West Indian girls and boys outperformed English students in all 3 areas, with Asian students doing the best (except in English language). Although English boys did better than English girls overall, the reverse was true for West Indian pupils – resulting in an overall ranking of West Indian girls, English boys, West Indian Boys then English girls. Because of differential drop out rates (higher for English students and for girls), the results were weighted by the '% of course enrollment in the last compulsory year appearing on the 16+ exam' – the superiority of West Indians, particularly the girls, remained.

Explanations for the different directions of the 2 groups' sex differences focused on the impact of family structure on aspirations for females and employment patterns. For example, English working class families are less likely to encourage their daughters in school, while West Indian women must often be the family provider (due to discrimination against West Indian males and family structure).

11. DUCKWORTH, D. and ENTWISTLE, N. J. (1974) 'The Swing From Science: A Perspective from Hindsight', *Educational Research* 17:1, Nov., p. 48-53.

Part of the study examined the attitudes towards maths and the sciences of 600 2nd and 5th form grammar school students. Four dimensions were considered: interests, easiness, freedom (e.g. to use own ideas), and social benefit (e.g. solve world problems, useful in everyday life). Overall female-male comparisons found fairly similar ratings though boys gave chemistry a better rating and girls gave biology a somewhat better rating. Boys and girls held similar attitudes towards physics except that 5th year boys saw more social benefits in it and 2nd year boys felt more freedom in it and found it more interesting. Maths attitudes differed by age – in the 2nd year girls were more favourable to it than boys, by the 5th year boys found it more interesting and felt more freedom. Few sex differences were detected on attitudes when arts, science and mixed choice (based on 5th year plans) students were examined separately (although considerable attitude differences were found across area-specialties).

12. EBBUTT, DAVE (1981) 'Science Options in a Girls' Grammar School' in A. Kelly (ed) *The Missing Half*, p. 113-122.

A case study was conducted on 3rd year girls as to factors related to science subject choices for subsequent years. Seven science teachers were also interviewed as to their theories of why girls took biology as the compulsory science rather than physics or chemistry. Many mentioned biology's relative easiness – it was predictable, straightforward, less quantitative, less cumulative and required learning/memorizing rather than understanding. Teacher also thought biology was more interesting to girls (e.g. the study of human anatomy suited girls' development stage), more career relevant (e.g. nursing), and received more positive press from parents, friends and teachers. Also cited was girls' passion for horses at this age. The girl students agreed with all these factors except the 'friend influence' and the 'love horses' theories.

An additional push towards biology was the negative image held of women scientists vs. the positive one for women in biology (e.g. nurses as glamorous). Using student essays on the topic, it was found that girls attributed negative stereotypic physical characteristics to women scientists. Yet other 'positive' traits were also listed – e.g. sensible, capable, reliable, calm, logical, orderly, dedicated. However, these traits are probably much opposed to the self-images of most 13 year old girls. Hence, images of women scientists may deter girls from choosing physical science courses.

13. EBBUTT, DAVE (1981) 'Girl's Science – Boy's Science Revisited', in A. Kelly (ed) *The Missing Half*, p. 205-215.

Through use of questionnaires and informal classroom discussions, junior form students from a rural comprehensive school (1975–76) developed lists of science activities/topics which were characterized as being either 'for girls' or 'for boys'. 'Girls topics' included making crystals, extracting plant scents, tie-dying from plant extracts and making chromatograms from felt nib pens. 'Boy topics' included cells & batteries, electrical circuits, elements (metals), air pressure, energy, and break-strain of copper wire. Some of these activities were clearly within sex role stereotypes. But additionally, girls' science seemed to have tangible end products which fulfilled some functional/decorative role – nearer craft type activities rather than understanding/controlling types of science. Girls were also more concerned with producing neat work books (again, an end product) often at the expense of involvement in practical work and/or concept development. Might this help explain girls' greater preference for biology with its heavy reliance on neat drawing skills?

14. FINN, JEREMY D. (1980) 'Sex Differences in Educational Outcomes: A Cross-National Study', *Sex Roles* 6:1, p. 9-26.

The study used IEA data collected in 1970 from nationwide samples of 14 year olds from England, Sweden and the U.S. to examine sex differences in science/reading achievement/attitudes. Although the sex differences were fairly consistent in the 3 countries, only the findings on science from the 2777 English pupils are discussed here. Female/male comparisons were made for single-sex (47) and mixed-sex (88) schools separately and for both 2nd and 3rd form students. Overall, boys outperformed girls on physics, chemistry and practical applications with virtually no difference in biology. However, girls from girls' schools surpassed boys from boys' schools in biology and chemistry. Boys' science attitudes also surpassed girls' on liking science, participating in elective science activities and perceived easiness of science – though girls were slightly higher than boys on perceived importance of science to society.

Single-sex school students outperformed mixed-sex students. (Students in single-sex schools did, however, come from higher SES backgrounds, had higher educational expectations, more same-sex teachers, more years of compulsory science, and more science teachers with university degrees). Sex differences in achievement and attitude were considerably larger in mixed-sex than in single-sex male-female comparisons, owing mostly to girls in girls' schools' better science performance. The sex difference within co-ed schools (but not for single-sex schools) increased with age. School variables differed between all-girl and all-boy schools. 63% of the boys' schools vs. 41% of the girls' schools had compulsory science until the 4th form or later – though girls' schools were superior in having 59% of their science teachers with university degrees vs. 45% for boys' schools.

Were girls in all-girl schools benefitting from the higher proportion of women teachers (87% vs. 41% in co-ed schools), the higher proportion of science teachers with university degrees (59% vs. 41%), higher social class backgrounds, higher educational aspirations, the role models of more successful teachers and peers and/or the absence of social pressure from boys' presence?

15. GALTON, MAURICE (1981) 'Differential Treatment of Boy and Girl Pupils During Science Lessons', in A. Kelly (ed.) *The Missing Half*, p. 180-191.

The teaching styles of 94 science teachers (from a sample of 94 city secondary schools) were observed for 23 different classroom behaviours. Cluster analysis gave 3 distinct styles. The Problem Solvers – teacher initiates/dominates/states problem, little pupil initiated/maintained activity, speculative/problem solving process rather than informational. The Informers – states facts, asks questions demanding recall of facts/their application/principles to solve problems with one right answer, little concern with data interpretation. The Enquirers (most closely identified with the Nuffield approach) – pupil initiated/maintained, students design experiments involving hypothesis testing/inference, practical work, demonstrations.

Half the teachers were PS's while only a fifth were E's despite its association with curriculum reform. As to their effect on student attainment, for both girls and boys, PS was best in physics, the 3 were equal for chemistry, and PS was best for recall in biology though E was best for data manipulation and problem solving in biology. Overall no style was best for student attitude. However, E was the only effective style for improving poor initial attitude in physics.

The differences in teaching styles actually used in biology (predominantly Inf) and the physical sciences (predominantly PS) may help explain differences in boys' and girls' attraction to the 2 areas (girls preferring facts to the insecurity of problem solving). If changes were made to optimize effectiveness – in physics, PS for attainment, E for attitude – the new styles would appear to be girls' least favourite. For biology, E was most effective, yet changes towards greater use of E in this 'girls' science' would go against girls' preferred style. Men teachers were also more likely to use PS – is this detrimental to increasing the proportions of girls in science?

16. GANNON, CATHERINE (1980) 'Girls' Underachievement in Science', *CORE* 4:1, March, Fiche 17.

The article reviews reasons why girls underachieve in science due to intellectual abilities, personality, socialisation, education practices, science options and career guidance. This is supplemented with a 1978 study of 100 5th and 6th form girls focusing on why they chose biology over physics and chemistry. Note, for example that national figures on 16+ exam entries show boys outnumber girls in physics (4:1 O-level, 8:1 CSE) and chemistry (2:1) though girls outnumber boys in biology (2:1).

As to intellectual differences, there is evidence of boys' superiority in numerical ability, problem solving and spatial ability – but their genetic basis and link with science achievement are tenuous. The personality of scientists (school children, university students and adults in science) are not those girls are socialized to. Also, girls' greater cooperativeness, docility, desire to please, and dependency makes them easily reinforceable, whether by mild approval/disapproval or their own minor successes/failures. Socialisation factors as toys, tasks and textbooks do not encourage girls' development of science/technical skills. The instructional methods and learning skills girls prefer and feel most secure with are those generally less used/required in science. Career guidance is often inadequate in science/engineering and sex stereotyping of occupations continues. The general image of science is also not very inviting to girls (e.g. masculine, absent-minded, ignorant of outside activities).

In the study, time-tabling and the '1 compulsory science' requirement led most girls to biology rather than physical science. They also chose biology because of its relation to human affairs – and not choosing physical science because it was too difficult, they disliked it, it wasn't necessary for a job and they would have felt different from other girls. Although they thought men teachers treated girls different than boys (ignored them or had low expectations), 3/4 still preferred men to women teachers.

17. GRAY, J. A. (1981) 'A Biological Basis for the Sex Differences in Achievement in Science?', in A. Kelly (ed.) *The Missing Half*, p. 42-58.

The focus is on the possible evidence showing that the well-documented sex difference in spatial ability is genetically based. Three types of arguments would be supportive: a sex difference in other species, a sex difference which began at an early age and evidence showing spatial ability to be a genetic characteristic. There is minor evidence of the first type – male rats are consistently superior to females in solving complex mazes, and male chimpanzees (but not females) practised aimed throwing of objects. Reviews of research showing an early sex difference reach divergent conclusions (however, sex differences emerging at a later age may still be biological – e.g. height differences). Much of the article is spent discussing evidence in the third category, (particularly the X-linked recessive gene hypothesis) and possible reasons for the contradictory results.

The author concludes that sex differences in science achievement, (presumably biologically-based) are not harmful and are indeed to be welcomed. Being poorer at spatial tasks does not lead to poor social or economic prospects for women. Note that society systematically rewards 'female' skills – verbal ability – more highly than 'male' skills – spatial ability – (e.g. compare pay levels of science administrators vs. actual scientists). And society does recognise individual women of outstanding spatial talents.

18. HARDING, JAN (1977) 'Sex Differences in Examination Performance at 16+', *Physics Education* 4:5, July, p. 280-288.

Sex differences in entry to and performance in 16+ exams (1974-76) were examined with comparisons made among school contexts and modes of assessment. More boys than girls took maths, chemistry and physics, while more girls than boys took biology. And while the proportion of boys taking biology is increasing, this is not so for girls and the physical sciences. Somewhat more boys than girls passed in maths and the sciences, while considerably more girls than boys passed English Language. However, boys' lower performance in language does not appear to constrain future achievement nor is it attributed to lesser ability, while girls' under-representation and poorer performance in maths and science is often accepted as demonstrating lower ability and is seen to account for their low involvement in the sciences later.

Maths/science exam performances differed by type of school and method of assessment. Boys surpassed girls in mixed-sex, comprehensive and grammar schools. Girls surpassed boys in single-sex schools (weakly supported). While boys from mixed-sex schools did better than boys from single-sex schools (weakly supported), girls did better in single-sex than in mixed-sex schools. As to mode of assessment, boys did better than girls on multiple choice questions, girls were superior to boys on essay questions, and no sex differences were found on structured papers. These contextual differences in exam performance suggest that female-male achievement differences do not reflect sex differences in ability. But will girls be even more disadvantaged in maths/science as we move towards more mixed-sex, comprehensive schools and multiple choice ('objective?') testing?

19. HARDING, JAN (1980) 'Sex Differences in Performance in Science Examinations', in Rosemary Deem (ed.) *Schooling for Women's Work*, London: Routledge and Kegan Paul, p. 86-97.

The 1974 GCE exam scores for a stratified sample of 1000 students were used to compare girls' and boys' performance in the sciences for Nuffield vs. conventional approaches, mixed vs. single-sex schools, and grammar vs. comprehensive schools. While no overall sex difference in pass rates was found, differences emerged for various school types (controlling for selectivity and sex-composition of school). In mixed-sex schools, boys clearly outperformed girls, while in single-sex schools girls outperformed boys slightly. Boys also clearly outperformed girls in comprehensive schools, but not in grammar schools, with girls actually being superior in direct-grant and independent schools. Girls pass rates were extremely high in these two. Girls clearly did better in girls' schools than in co-ed schools while the reverse was somewhat true for boys. Comparison between Nuffield and conventional approaches yielded mixed results.

Girls studying science seem to be most disadvantaged in mixed-sex, comprehensive schools – the dominant trend today. Do teacher and student expectations for all students become more traditional because of greater proportions of working class students and less academically able students (for whom the traditional sex role ideology is perhaps more relevant)? Overall, fewer girls than boys select science courses (e.g. 4:1 for O-level physics, 8:1 for CSE) and careers. Two important factors seem to influence girls' choice of school subjects and their performance in them: the masculine/feminine image of the area and the level of commitment to a career outside the home. The masculine image of science can be clearly observed in the relative numbers of each sex represented in science courses, teaching staffs, scientists shown in the media, and textbooks and in the masculine examples used.

20. HARDING, JAN (1981) 'Sex Differences in Science Examinations', in A. Kelly (ed.) *The Missing Half*, p. 192-204.

National figures for boys' and girls' entry and pass rates were examined for the 1974 CSE and O-level exams. Although maths is a compulsory subject, fewer girls than boys attempted O-levels in maths, instead doing a CSE (actually more girls took O-levels in biology than in maths). Physics was the 3rd most popular subject boys attempted (after English and maths) – with boy/girl ratios of 4:1 and 8:1 for O-level and CSE exams.

Pass rates for the 3 sciences for both Nuffield and conventional syllabi across types of schools were compared. There was no overall support for boys' superiority in science. (However, since there were generally more boy than girl entries, the latter was a more select group). Boys surpassed girls in mixed-sex and comprehensive schools, while girls were superior to boys in single-sex, maintained, grammar, direct grant and independent schools. Girls in girls' schools did better than those in co-ed schools while the opposite was true for boys. (Note, however, that the trend is towards more co-ed comprehensive schools).

Girls' selection of science is discussed in the context of a 2-dimensional model for subject choice – the perceived masculinity/femininity of the subject/occupation and the degree of commitment to a career outside the home. 1) Feminine activity/low career commitment (overrun with women, e.g. secretaries, hairdressers). 2) Feminine activity/high career commitment (e.g. teaching and nursing for women; music, dance, haute cuisine for men – acceptable for males if they assume a leadership role within the activity). 3) Masculine activity/high career commitment (expected for males – e.g. physical science). 4) Masculine activity/low career commitment (no place for males, i.e. 'lacks ambition'). A female interested in or good at physics, but not committed to a career in it is not catered to, however, since the physical sciences generally assume a vocational role in school curriculum rather than being part of a general liberal education. To become a physical scientist/engineer/mathematician, females must defy convention on both dimensions.

21. HARVEY, T. J. (1979) 'Mixed Ability Teaching in Physical Science', *Educational Research*, 22:1, Nov., p. 60-61.

Verbal reasoning test scores were compared with science attainment (on 4 objective tests) for 240 first year comprehensive students in mixed ability classes. Of the more able students, boys did significantly better than girls while the reverse was true for the less able students. However, both boys and girls underperformed with able girls seriously underperforming.

22. HEARN, MICHAEL (1979) 'Girls for Physical Science: a School-Based Strategy for Encouraging Girls to Opt for the Physical Sciences', *Education in Science* 82, April, p. 14-16.

A comprehensive school teacher briefly discusses this school's strategies used to promote the physical sciences for girls – constant concern rather than extensive time input was the emphasis. Pupil-based efforts included in-class discussions (with third year students) on the paucity of girls in physical science classes, the increasing numbers of women choosing careers, and the importance of the physical sciences even if studying biology. Strategies for dealing with parents included a special evening programme for third year pupils' parents to discuss issues as the selection of subjects, their influence on career prospects (and specifically on girls and science), and a demonstration of facilities and types of work in various subjects. Non-science staff such as the careers officer, the director of studies and third year personal tutors were involved and specifically discussed with students topics such as criteria to use for subject choices, their influence on career possibilities, and girls' restricted range of choices. Exhibits/films were shown to pupils and parents (using female scientists/demonstrators) focusing on sex equality in science ability, possible science careers and the necessity of physical science courses for a variety of careers, even in biology. Science teachers in particular watched for girls' understanding of the material and keeping up with the work.

23. HUTT, CORINNE (1979) 'Why Do Girls Underachieve?' *Trends in Education* 4, Winter, p. 24-28.

A survey of the sex role attitudes of 200 13-16 year olds was conducted, comparing students in single-sex and mixed-sex schools. Several findings directly concerned maths and science. Both sexes thought maths was an important subject for boys, but not for girls. The reported 'worst' vs. 'best' subject were maths vs. English for girls in co-ed schools, foreign language vs. history for girls in girls' schools as well as boys in co-ed schools, and the natural sciences (both worst and best) for boys in boys' schools. This supports other studies which find that mixed-sex schools polarise students' performance and subject preference along sex role lines, particularly for girls. Sex-stereotyping of jobs, roles and abilities in general was more evident in mixed-sex than single-sex schools.

24. JAHODA, GUSTAV (1979) 'On the Nature of Difficulties in Spatial-Perceptual Tasks: Ethnic and Sex Differences', *British Journal of Psychology* 70:3, Aug., p. 351-363.

Primary school children aged 7, 9 and 11 were tested on 3 Piagetian tasks to compare Scottish and Ghanaian children's spatial abilities. For the 72 Scottish children (from semi/unskilled occupation families) boys were superior to girls on block construction, but no sex differences were found for mental rotation and shape assembly tasks.

25. JENKINS, E. W. (1974) 'The Scientific Education of Girls since 1902' *The Durham Research Review* 5, Spring, p. 873-886.

In the early part of the century sex differentiation was seen as desirable and was built into the curriculum. In girls' schools practical instruction in the domestic subjects was compulsory; physics, chemistry and manual instruction were often replaced by botany and general science; and mathematics/science instruction was offered only a few hours per week. In the post-war period as the importance of science was clearly being emphasized, scientific/technological 'manpower' was in great demand and an increasing emphasis was placed on science education for girls. Girls flocked to biology and general science, though not the physical sciences (such courses were not even offered in the 1960's). Explanation for girls' alleged aversion to study science have been offered since the turn of the century but most lack solid research information. Staffing/facility deficits in girls' schools was commonly cited as a prime problem – yet mixed sex schools did not seem to alleviate the problem. The lack of economic/career incentive for girls in the physical sciences seems plausible ('women's' fields as nursing may explain the popularity of biology). Other explanations discussed include possible sex differences in mathematics ability, beliefs about the female role and the image of science, parental expectations of marriage, and the flexibility of a particular career.

26. KELLY, ALISON (1975) 'Why Do Girls Study Biology?', *School Science Review* 56:196, March, p. 628-632.

Up to A-levels more girls than boys take biology. And girls are much more likely to take biology than the physical sciences. Why? Is it because biology is nurturative and concerned with people? To test this a sample of 1970 Scottish university entrants rated the importance of various aspects of their ideal job including 'working with people rather than things'. Though women and arts/social science students thought it somewhat more important than men and biology/physical science students, there was no difference between those women in biology and those in the physical sciences. Though this data did not support the traditional hypothesis, perhaps girls are drawn to biology because they wish to be concerned with people not necessarily work with people.

Other explanations for biology's popularity are considered. Is biology a compromise with society's expectations for women (physical science is prohibited, social science is respectable and biology falls in between)? Do girls have inadequate opportunities to study other sciences (e.g. a shortage of physical science facilities/teachers channels girls where the openings are)? Is biology seen as more relevant to the average girls' life (motherhood, nursing)? Are girls less confident of their ability and thus choose biology before they realize their future educational and occupational possibilities? Is it because biology is introduced in primary school (nature study) while physical science is new (especially to girls who lack early non-school experience in the area)? Students see biology as less difficult/abstract/theoretical and more descriptive than physical science. Does this make it more attractive to girls; (being more reinforcable by good marks and more discouraged by difficulties and bad marks)?

27. KELLY, ALISON (1976) 'Women in Science: A Bibliographic Review', *Durham Research Review* 7, Spring, p. 1092-1108.

This is an extensive review of British, American and Australian research concerned with explaining the paucity of women in science in the western countries. The highlights: considering intellectual ability, spatial ability differences appear to be the most substantiated sex difference – though if this were the only explanatory factor we should see 2 females for every 3 males in the sciences. The personality characteristics of scientists are more closely paralleled by males (and the prescribed male role) than by females; however, female scientists (and girls with high spatial ability) tend to have the 'typical scientist's personality' (due to socialisation?). From family and occupational characteristics of women scientists, it appears that 'women still have to choose, if not between marriage and a career, then between children and a career'. Women scientists also appear to face difficulties and discrimination on the job – being in lower ranked jobs, fearing the competitiveness of promotions, lacking colleagial encouragement, facing overt discrimination as well as informal exclusions and being expected to fit into male work/career patterns.

Science career interest emerges early and girls are not as drawn to it as boys. Girls are less drawn to careers in general (boys are even more conservative toward women in careers) and tend to avoid those with long training and those that don't deal with people. Choice of school subjects also often has to be made early and girls are less likely than boys to select physics and chemistry at O-level – falling proportionately further behind through the educational system in all the science/technology fields. Factors affecting their subject choice include the stereotype of science as 'male' (textbooks, staff and student opinion, actual numbers in science), a shortage of qualified teachers, forced choice of subjects at puberty, unwillingness to compete with boys, the difficulty of science as a subject (amount of work, severity of grading, high conceptual level), the teaching style (favouring boys), the absence of stress on the social implications of science, the absence of interest (independent of ability) and mixed-sex schools.

28. KELLY, ALISON (ed) (1981) *The Missing Half: Girls and Science Education* Manchester: Manchester University Press.

This book is a diverse collection of 20 original papers, both theoretical and empirical, addressing such issues as biological vs. socialisation vs. socio-political explanations for sex differences, attitudinal factors in subject choice, choice versus channelling out of science, teacher treatment, differences in science examination results, girls' versus boys' science classwork, the image of science, sex-typing in schools, and student and teacher personal viewpoints on the topic. Both the origins of girls' under-achievement in science and proposed solutions are explored. (The articles are all annotated separately here).

29. KELLY, ALISON (1981) 'Girls and Science Education: Is there a problem?', in A. Kelly (ed) *The Missing Half*, p. 1-19.

The introduction to the book presents current data to demonstrate the underrepresentation of females in science at all levels of education. This is particularly true in physics and chemistry, though not so in biology until beyond O-level. Although there are some formal barriers to girls' entry to science, the informal barriers are considerably more extensive. The crucial period for intervention to alleviate 'the problem' (getting/keeping women in science) is in the middle school years; beyond that the strategy is a more general one of keeping women in the educational system.

International comparisons demonstrated that although women's under-representation in science education was extensive, it was by no means universal, and the range was considerable (e.g. women were 5% of science students in Saudi Arabia, but over 60% in Poland). But unlike other regions, West Europe and Africa's lack of women in science was not directly due to women's under-representation in education overall.

30. KELLY, ALISON (1981) 'Sex Differences in Science Achievement: Some Results and Hypotheses', in A. Kelly (ed) *The Missing Half*, p. 20-41.

The 1970 IEA Science Survey found that boys scored considerably higher than girls in all 19 countries. This study reanalysed the data from the 14 year olds in 14 developed countries including England and Scotland. Three widely-discussed non-biological explanations were examined: the culture/socialisation hypothesis (i.e. girls' science achievement is not socially expected or encouraged), the school hypothesis (i.e. science is taught in a way more suited to boys than girls), and the attitude hypothesis (i.e. girls have less favourable attitudes towards science). Using various proxy measures to test these, only the attitude hypothesis was partly supported by the data.

For the first hypothesis comparisons of girls and boys across cultures and classes found that girls in some countries/classes did considerably better than the boys in others and/or better than the overall male-average. Yet within each subject the sex differences were fairly uniform across cultures/classes (smallest in biology, largest in physics) and did not seem to be influenced by the proportion of women science students (13% to 54%).

Several school organizational factors and teacher characteristics (e.g. sex of teacher) were examined to test the 2nd hypothesis, but no variable explained the sex difference in achievement consistently across countries.

On the third hypothesis, science attitudes (liking science-based activities, expectations of success, and effect of science on the world) were correlated with achievement in science (controlling for ability), and girls did have less favourable attitudes towards science than boys. Also the variation among countries of both attitude and the sex difference in attitude suggests the possibility of improvement. However, boys' science achievement was better than girls' with equally favourable attitudes.

31. KELLY, ALISON (1981) 'Science Achievement as an Aspect of Sex Roles', in A. Kelly (ed) *The Missing Half*, p. 73-84.

The main theories of socialisation are discussed as they apply to sex differences in science achievement. Social learning theories (reinforcement and observation/imitation/role modelling) see the child as basically passive, being moulded by external forces (e.g. 'pressured' to conform to an image). Cognitive development theories see the child as actively trying to make sense of the world (e.g. developing categorization rules such as the sex roles), motivated to achieve competence rather than reward. Each suggests different strategies for change. The latter appears more plausible.

The reinforcement/imitation theories – more popular in the sex role literature – would explain girls' lower achievement in science by such factors as the absence of role models to imitate (textbooks, scientists, science teachers, parents), differential approval/disapproval for 'sex-appropriate' mechanical/scientific toys, hobbies, and household tasks, and differential reward/punishment for success/failure in science. In many ways these theories are not sufficient to account for observed sex differences in science (such as the consistent sex difference cross-culturally in spite of cultural variation).

The cognitive development theory explains the sex differences as primarily due to science achievement being seen as masculine (e.g. due to textbooks, media presentations of scientists as male). Girls do not see success in science as compatible with their definition of femininity (rather exaggerated and over-simplified at early ages) and are thus less motivated in science. This theory helps explain, for example, why sex-typing can occur in spite of non-sexist upbringing, or how sex-stereotypes can be maintained in spite of exceptions. The increasing sex gap in science from 10-14 can be attributed to both a resurgence of interest in (and conformity to) sex role categories at puberty as well as a feedback loop due to the cumulative nature of science (boys are initially more comfortable with science, develop better attitudes, achieve in it and get positive feedback, and are thus more motivated for further achievement and have developed a better foundation for later science).

Change strategies should include changing the masculine image of science, and convincing young girls that 'cross-sex' behaviour (and science in particular) is not only pleasing to adults but demonstrates competence in the female role.

32. **KELLY, ALISON** (1981) 'Choosing or Channelling?', in A. Kelly (ed) *The Missing Half*, p. 123-138.

Using the 1975-76 Scottish Data Archive survey of school leavers, the article examines sex differences in science subject choice and student reported reasons for this. The Scottish educational system traditionally values a broad education and delayed specialisation. However, comparison with English data revealed similar patterns of sex differences in taking science. More boys than girls continued in science at all levels (up to and including FE). Of those leaving with any H grades, ½ of the girls but only ¼ of the boys had no science since 14. Of those with H grades, ¼ of the girls but only 7% of the boys had no science since 14, and 2/3 of the girls with minimum university entrance qualifications had had only 1 science O-grade. Higher ability boys took physics and chemistry, while the girls took biology.

In investigating reasons students gave for subject choices, girls and boys were similar in most often mentioning liking/not liking science. Other influencing factors mentioned: perceived usefulness for jobs and FE, time-tabling conflicts (noted especially by girls), not being allowed to drop science (noted especially by boys) and being good at it or finding it easy (particularly boys). Boys were more likely to see science as useful for a job and necessary for a balanced education – girls were obviously already limited by looking towards traditional jobs/roles. Comparing students' occupational choices with their perceptions of science's usefulness, boys tended to over-estimate its value, girls underestimated.

33. **KELLY, ALISON** (1981) 'The Pupils' Viewpoint', in A. Kelly (ed) *The Missing Half*, p. 232-245.

The article summarizes and excerpts from 300 women students descriptions of their experiences concerning science (in response to notices in women's and science educators' newsletters). A number of common situations were reported. Girls felt isolated and ignored or held up as different in science classes (being 1 of a few girls in a class/group, segregated, not expected to understand) and therefore felt self-conscious. Science was felt to be a boy's subject. Much 'fighting back' was necessary to get into and stay in science (e.g. teachers, parents, self). During puberty it became especially difficult to do well and talk in science classes when boys were around, or sometimes even with male teachers (e.g. interest in boys more than class, concern with 'his' opinion, fear of being seen as a brain). Biology seemed a better subject choice than physics/chemistry (more interesting, understandable, relevant and concerned with people; less masculine, mathematical, tedious and anxiety-producing; and concerned with learning facts vs. understanding principles). Girls reported feeling squeamish about aspects of science (the smells of chemistry, cutting up animals). Some teacher behaviours were discouraging (even bright girls were't taken seriously, male teachers talked 'male' talk). Timetabling caused difficulties (conflicts, forced choices, too many other choices). Girls also reported that the career relevance of physics/chemistry should be stressed (even for traditional female fields).

34. **KELLY, ALISON** (1981) 'The Teachers' Viewpoint', in A. Kelly (ed) The Missing Half, p. 246-263.

Teachers responded to an ad in the Association of Science Educators newsletter asking for their opinions as to why girls underachieved in the physical sciences and what could be done. They gave little support to innate differences, but sex differences in intellectual style was frequently mentioned. Popular explanations also included poorer facilities in girls' schools, few role models for girls in science, little encouragement from home, the masculine image/bias of science and girls' greater need for reassurance and encouragement in general. For example, girls feared and hesitated working with unfamiliar objects and needed to be shown, watched and encouraged. (However is it actual or perceived lack of familiarity, e.g. isn't the bunsen burner really a type of cooker?). Girls are also likely to answer only when they have the right answer or a factual answer, while boys are more willing to guess or give opinions.

Girls were more likely to see physics and chemistry as irrelevant to future careers (e.g. traditional family/career roles and/or lack of career opportunities in science for themselves). Respondents also noted the detrimental effect of the shortage of women science teachers – not solely for their importance as role models – but because male teachers are less likely to place value on girls' greater neatness of work or to use 'female' or neutral examples. Science lessons could also be broadened to include things girls do best (as opposed to things boys do best as is currently the practice) such as library research, essay writing and clear instructions (vs. discovery methods).

35. KELLY, ALISON (1981) 'Retrieving the Missing Half', in A. Kelly (ed) *The Missing Half*, p. 276-297.

The article concludes the book of readings drawing from the ideas and research in it to suggest school policy changes aimed at increasing the proportion of girls in the physical sciences. Schools do make a difference – the proportions of girls in the physical sciences varies from 2% to 66% across the country. Within the classroom girls and boys need not be treated identically – by secondary school they are different (personality, background experience, place in society – whether biological or social in origin). Equal emphasis should be placed on aspects/approaches to science where girls do well. Girls are neater, more conscientious and tolerant of routine, like groupwork, are interested in people, have higher verbal ability and are less self-confident. Hence they could use greater attention and reassurance, more specific direction and greater linking of the abstract to the real world. Examples should also be drawn equally from their world of experience (e.g. a tin opener vs. a car jack).

School efforts should include examining possible sex bias in general and specifically in science staffing, textbooks, careers advice, exam questions (examples and essay vs. multiple choice), packaging of courses together, and teaching styles. Schools should also try to combat the masculine image of science and teach domestic science truly as a science (also changing its image). Student freedom to drop science should be postponed until after puberty. Timetabling, remedial science classes (leisure, no-pressure classes), early unbiased careers advice (pointing out long-term implications and the importance of science even for 'female' jobs), contact with women scientists (visits and in career material to show they exist and are 'normal'), crafts/technical job opportunity exposure for girls as well, general sex-stereotyping, and discrimination in single-sex schools are all issues that should be addressed.

Wider relevant societal issues include changing both sex roles and science. Notions of femininity (e.g. dependence, no career) and masculinity (e.g. not helping with housework and child-care) should be altered and expanded. Images of science as masculine and impersonal are not intrinsic to sciences – the physical sciences can become more humanistic, and inviting to females.

36. KEYS, WENDY and ORMEROD, M. B. (1976) 'A Comparison of the Pattern of Science Subject Choices for Boys and Girls in Light of Pupils' Own Expressed Subject Preferences', *School Science Review* 58:203, Dec., p. 348-350.

The science subject choices of 1373 3rd year students from 28 schools (1972–74) were examined in relation to subject preference and sex. Overall, considerably more boys than girls took physics, somewhat more boys than girls took chemistry and considerably more girls than boys took biology at O-level. However, when students were divided in 'liking' and 'disliking' a subject (i.e. above and below the median on the Brunel Subject Preference Grid) and compared for subject choice, several patterns emerged. Not surprisingly students who 'liked' a subject were much more likely to take further courses in it than those who didn't – but the sex stereotype of subjects intruded. (For example, of those who liked physics, 95% of the boys but only 69% of the girls took physics later). Of those who disliked a subject, a significant proportion still took further courses in it if it fitted with the sex stereotype (e.g. of those who disliked biology, 62% of the girls but only 24% of the boys took biology).

Thus factors other than personal preferences influenced students' subject choices, e.g. a significant number of boys who dislike physics take it, while a significant number of girls who like it don't take it (and vice versa for biology).

37. KEYS, WENDY and ORMEROD, M. B. (1976) 'Some Factors Affecting Pupils' Subject Preferences', *Durham Research Review* 7:36, Spring, p. 1109-1115.

A sample of 348 GCE-stream 14 year olds from 9 grammar and 2 comprehensive schools was used to examine subject preferences, perceived subject easiness and subject choice in the 4th year. The focus was on maths, biology, chemistry and physics. Achievement (much more so than ability), subject preferences and perceived easiness were all correlated for each of the 4 areas (e.g. those who did well on the end of year maths exam like it relative to other subjects and thought it was relatively easy). Students were also likely to prefer a subject if they like the subject teacher.

Girls and boys differed in their preference for each of 15 subjects. Boys ranked physics 3rd, maths 4th, biology 9th and chemistry 10th, while girls ranked biology 6th, maths 8th and chemistry and physics 14th and 15th. They also differed on their easiness ratings – girls gave biology 8th, maths 11th, and physics and chemistry 14th and 15th. It was also found that those subjects considered most difficult and least popular (e.g. chemistry) were those where preference was most strongly influenced by student's earlier achievement.

38. KEYS, WENDY and ORMEROD, M. B. (1977) 'Some Sex-Related Differences in the Correlates of Subject Preference in the Middle Years of Secondary Education', *Educational Studies* 3:2, June, p. 111-116.

The sex differences in subject areas seen at O-level go back at least as far as middle school where subject choices are made. This study looked at the subject preferences of 348 14 year olds in GCE streams (from grammar and comprehensive, co-ed and single sex schools) as they related to perceptions of subject easiness, relative attainment (exam marks), and 'gender' of subject.

While girls and boys generally agreed on the rank ordering of easiness of the 13 subjects, they disagreed on the ordering of subject preference. Overall, perceived easiness and preference were closely related for girls but not for boys. However, looking at subjects separately, easiness did affect preference for the maths/science subjects (.5 to .7) equally for boys and girls in biology and physics, though more so for girls than boys in chemistry and maths. While subject attainment did affect preference in the 4 science areas (.2 for biology to .4 for chemistry), it had less impact than perceived easiness; and no sex difference was found.

The 'gender' of subjects (developed from sex differences in subject preference) showed physics, chemistry and maths to be the most masculine (1st, 3rd and 4th) with biology being neutral (7th out of 13). This gender hierarchy was highly correlated (.77) with actual 'gender spectrum' (i.e. the proportion of boys in each O-level exam subject). Gender hierarchy was even more highly correlated with perceived easiness (–.88 for girls' easiness ranking, –.62 for boys'). That is, 'male' subjects are considered difficult, 'female' subject are easy. Perceived easiness thus appears to be a key factor in girls not taking physical sciences.

39. LEVERETT, S. M. (1979) 'Observed Sex Differences in Attainment in a Computer Studies Examination', *Computer Education* 32, June, p. 31.

CSE examination results in computer studies were compared for 500 girls and boys from 35 schools across the country. Of the 49 items, boys scored significantly better than girls on 16 items (some had quite large differences) with no significant differences on the others. Of these 33 non-significant differences girls were marginally superior on 6 items (such as doing flowcharts and stock control techniques), and boys were marginally superior on 25 items.

40. MURPHY, ROGER J. L. (1978) 'Sex Differences in Examination Performance: Do These Reflect Differences in Ability or Sex Role Stereotyping?', *Educational Review* 30:3, p. 259-263.

The 1976 O-level examination entries and pass rates were compared for girls and boys. Girls made up a higher proportion of the entrants and had higher pass rates in non-science subjects such as literature, religion and foreign language. In maths, chemistry and physics, however, girls made up only 43%, 33% and 23% of the entrants, respectively – and boys had only slightly higher pass rates (i.e. 60% vs. 56%, 61% vs. 60% and 59% vs. 58% respectively). In biology girls were 59% of the entrants, but boys surpassed them in performance – 61% vs. 56% had passes.

Does this male superiority in maths/science reflect real sex differences in ability (innate or learned) or instead, the way examinations are set. Is it question wording (e.g. examples used)? 'Objective' multiple choice testing favours boys and essay questions favour girls' verbal ability – is this difference a factor? Are there a greater proportion of spatial ability questions (favouring boys) as opposed to computation questions (favouring girls)?

41. NEWTON, PEGGY (1981) 'Who Says Girls Can't Be Engineers?', in A. Kelly (ed) *The Missing Half*, p. 139-149.

In 1977–78 the Engineering Industrial Training Board set up an experimental program to recruit/sponsor engineering students. Of the 3 background areas important to entry into engineering, (maths, physics and crafts/technical), girls were considerably behind boys in having experience in the latter two. Reasons found for girls not taking physics, woodwork, metalwork and technical drawing included not being allowed to, lack of or shortage of facilities/staff, social pressure (e.g. having to put up a fight, being the only girl choosing the class) and traditional career guidance. Girls also reported not being exposed to engineering careers until it was too late for appropriate subject choice.

42. ORMEROD, M. B. (1971) 'The Social Implications' Factor in Attitudes to Science', *British Journal of Educational Psychology* 41:3, Nov., p. 335-338.

A national representative sample of entire 3rd year groups from 17 schools was examined as to attitudes to science (having two factors: science as a school subject and the social implications of science) and subject preference. It was found that the social implications of science factor had a stronger relationship with choice for/against a science option for girls than for boys. The implications for increasing the number of girls continuing in science would be to include more 'social'/real world topics in the science curriculum (currently thought to be unimportant at the secondary level).

43. ORMEROD, M. B. (1973) 'Social and Subject Factors in Attitudes to Science', *School Science Review* 54:189, June, p. 645-660.

A two-part science attitude scale was developed – a general school science component and a social implication component. It was administered to 500 3rd year students from 14 schools of varying types in 1969–70. It was found that the first component (e.g. science is/is not useful, exciting, interesting) was correlated with students electing optional science courses for both girls and boys. The second component (e.g. science makes life easier, costs too much for society, is man's worst enemy) was related to selection of science courses only for girls. Might this suggest that more girls would take science courses if positive societal implications of science were emphasised in earlier secondary school?

44. ORMEROD, M. B. (1975) 'Subject Preference and Choice in Co-Educational and Single-Sex Secondary Schools', *British Journal of Educational Psychology* 45:3, Nov., p. 257-267.

The subject preferences and subject choices of a national sample of 1204 pupils in 19 secondary schools were examined as to the effect of sex-stereotyping, attitude toward teacher and single/mixed-sex school organisation. Based on students' subject preferences and choices, maths, physics, chemistry and geography were 'male' subjects while biology, languages and arts were 'female' subjects. There was an even greater sex-polarisation of subject preference/choice in mixed-sex schools as compared with single-sex schools. However, since subject preference was highly correlated with teacher popularity, the polarisation of subjects choice when other sex students are present may not be explained solely as a reaffirming of one's sex role and making relative comparisons across sex in co-ed situations (as Dale suggests). Relevant intervening factors may include teaching style and the neglect/emphasis of certain topics which may vary between type of school (i.e. co-ed vs. single-sex). Much research in science education suggests a sex difference in learning styles and response to various teaching strategies and teacher behaviour. Thus teaching boys and girls side by side may elicit teaching styles and selection of topics which may encourage boys but discourage girls, where as teaching in single-sex schools may cater to the sex of the pupils.

45. OMEROD, M. B. (1981) 'Factors Affecting the Science Subject Preferences, Choices and Attitudes of Girls and Boys', in A. Kelly (ed) *The Missing Half*, p. 100-112.

The article summarizes the findings from many of his other studies on science which focus on 14 year olds – the age when crucial decisions of subject choices are made. Many variables influence subject preference/choice, often subtle, unstable and interacting together.

Students in co-ed (vs. single-sex) schools made more sex-polarised subject preferences/choices (especially in maths/science) perhaps as a means of asserting their sex roles at puberty. Girls were less likely to match their choice to preference (i.e. liked physics/chemistry but dropped it, didn't like biology but took it), perhaps due to their insecurity at entry into the male preserve, anxiety about the perceived difficulty of physical science, advice from others or hidden selection due to staff/facilities shortage.

Perceived difficulty of a subject was correlated with girls' subject preference (but not boys') even more so than past attainment – and chemistry/physics were generally rated as relatively difficult. Views of the social implications of science affected choice of physics/chemistry but not biology. The practical, personal payoff was important for boys while the humanitarian payoff was important for girls.

Middle school science experiences influenced later subject choices – e.g. girls nurturing animals had a positive effect while working with other than domestic animals had a negative effect. Early practical work was helpful to boys but hindered girls who preferred to watch. Early liking of maths and perceived difficulty of science were important predicators of girls' preference for physics later. Early parent interest had a negative effect on boys' liking of physical science (perhaps pressure from parents' transferring their own ambitions to sons?). Boys' and girls' interests in science were already differentiated in primary school – girls liked nature study, boys liked space study.

Suggestions for change include postponing subject choice (since at puberty especially, many non-academic factors – as gender – predominate) and balancing biology and physical science up to age 16; revise the syllabus to reduce the level of difficulty of physics/chemistry in line with other subjects; and emphasize the importance of science to society, improving its tarnished image as menace to society/humans/nature.

46. ORMEROD, M. B. with BOTTOMLEY, JENNIFER M., KEYS, WENDY P., and WOOD, CHARLES (1979) 'Girls and Physics Education', *Physics Education* **14**, p. 271-277.

This article summarizes the findings of the authors' other work. 1) Biology differs from physics and chemistry (more girls, less difficult, less undesirable social implications). 2) Career decisions are made at an earlier age in science than other areas. 3) By 14, the social implications of science may already influence science choice. 4) Teacher-pupil interaction appears to be a powerful yet unstudied influence. 5) The strongest and best documented factor influencing subject choice – especially for girls – is the perceived difficulty of the subject.

The female/male biology/physical science dichotomy is already suggested in primary school preferences – girls for nature study, boys for space study. Co-ed (as compared with single-sex) schools further polarise students' subject preferences along 'sex-appropriate' lines. Although correlated, subject preference and actual subject choice often diverge (especially for girls) when 'sex-appropriateness' is considered, (e.g. many girls who disliked biology take it, and/or liked physics but drop it). However, girls expressing an early preference for biology and boys for physics virtually always later took the class – less so for the opposite case – and least so for students preferring chemistry. Actual subject choice also correlated with the perceived social implications of science (value to self and community, effects on the environment/human race), – much more so for physics and chemistry than biology, however.

Physics and chemistry are rated as the most difficult of 15 subjects by both sexes. And perceived easiness was strongly related to subject preference for girls (.77), less so for boys (.32). It was also considerably more important than past attainment in predicting subject preference. Physics students of both sexes are more spatially intelligent and verbally accurate though less verbally fluent than non-physics students. Girls in physics tend to be introverts, have an early liking of maths and have much greater educational ambitions than either boys in physics (who tend to be extroverts) or other girls.

In conclusion, it is recommended that such early science specialization not be allowed. Even without this change, more girls might be led to physical science by early emphasis on the positive implications of science for society, attempts to alter girls' perceptions as to the difficulty of physics/chemistry; reconsideration of teaching and learning styles in physical science (which now favour boys), and consideration of how the beneficial aspects of single-sex schooling for girls might be used.

47. ORMEROD, M. B. and DUCKWORTH, D., (1975) *Pupils' Attitudes to Science: A Review of Research*, Slough: NFER.

This book reviews British, American and Commonwealth literature on science attitudes (including a 30+ page bibliography) much of which is relevant to sex differences in science. The biology/physical science dichotomy for girls and boys is attributed to various factors: girls' preference for living matter, boys for things; biology as a compromise (with sex role expectations) for those girls interested in science; different personality types drawn to biology (more 'feminine', as with arts) vs. physics (more 'masculine', like maths); the physical sciences are seen as masculine and a male preserve; physics involves too much maths; biology is more nurturative, humanitarian and focused on people; and biology is seen as more beneficial/less harmful to society than physical science. Further, girls are more easily influenced by perceived difficulty of a subject – and the physical sciences are rated as the most difficult, taken by the most intelligent pupils, have an overloaded syllabus and the hardest grading.

Different teaching/learning styles are favoured by boys and girls (e.g. discovery vs. demonstrations, rote learning, practical work, pupil-centred, projects, case studies) due to a variety of factors including differing cognitive styles. Whether innate or acquired, girls' and boys' cognitive styles differ by middle school (e.g. spatial/quantitative vs. verbal bias), which may affect preference for and performance in different sciences. For example, girls tend to want to memorize difficult material while boys try to master the underlying principles. And girls' lower curiosity and lack of confidence makes them less favourably disposed to discovery learning. Thus biology may seem more attractive to them than physics or chemistry.

Science interest is aroused at an earlier age than other areas. Since few primary teachers (mainly women) have much maths/science, out-of-school science experiences (which girls often lack) may contribute greatly. The sex-structure of the school is also important – being educated with the other sex further polarises subject choice (girls to biology, boys to physical science) and performance (girls do better in all-girls' schools, boys do better in co-ed schools somewhat). This could be attributed to co-ed girls using subject choice as a way of asserting their sex roles, their greater likelihood of seeing physical science as a male preserve, their concern for what others think (i.e. male classmates), their fear of feeling odd (e.g. being in the definite minority in physics class) or to teachers in girls' schools catering to girls' preferred teaching/learning styles (biased toward boys in mixed-sex schools).

48. PREECE, MURIEL (1979) 'Mathematics: The Unpredictability of Girls', *Mathematics Teaching* 87, June, p. 27-29.

As part of a 5-year project, a sample of 1250 2nd year students from 5 comprehensive schools was used to study whether changes in teaching behaviours would improve maths skills and attitudes (interest, anxiety, perceived usefulness, perceptions of parent attitudes and perceived sex appropriateness). Teachers in some classes were to show positive attitudes towards the girls, use non-stereotypic examples, encourage girls to participate along with the boys in practical exercises and use specially designed materials.

It was found that, overall, girls and boys did not differ significantly in computation at either testing time, though boys were superior on problem solving, especially at year's end. A notable exception was on 'domestic' problems which favoured girls – girls' performance especially was strongly influenced by the context of the problem. There were no overall sex differences in maths attitude at the beginning – boys were more self-confident and had higher expectations of success – girls were more conscientious, had a greater intrinsic interest in maths and a greater need for teacher support – both rated maths as important and neither saw it as a male preserve. By the end of the year, however, boys' attitudes improved while girls' dropped. Boys no longer felt maths was easy, but as a challenge they could tackle. Girls thought themselves hopeless in maths, didn't expect to succeed, nor felt anyone else did either.

For the boys, problem solving, computation and maths attitudes were all correlated, especially the 2 maths skills. For girls, however, computation and problem solving were only moderately correlated, but maths attitude was not related to either – i.e. girls' liking (confidence, anxiety, etc.) of maths cannot be predicted by their success in it. Clearly there is a need to begin work on the problem at a much earlier age.

49. SARAGA, ESTHER and GRIFFITHS, DOROTHY, (1981) 'Biological Inevitabilities or Political Choices? The Future for Girls in Science', in A. Kelly (ed) *The Missing Half*, p. 85-97.

Biological and socialisation theories explaining females' underachievement in science are criticized in favour of more macro political/structural/cultural explanations – i.e. women's position in society and the status and nature of science itself. The biological determinist position is not adequately substantiated, draws too heavily from inferences from animals, narrowly focuses on spatial ability while ignoring its possible social basis, ignores the importance of more general maths skills and non-ability components of achievement (e.g. motivation, anxiety). Socialisation theories, while not unimportant, may easily lead to false optimism (i.e. socialisation can easily be altered) or false pessimism (i.e. failure to achieve significant changes quickly leads to a conclusion of biological determinism).

Until the structural basis of women's oppression is challenged/changed, they will be unable to (and/or feel the pressure to) take advantage of 'equal' academic/occupational opportunities (e.g. dual role demands, the sexual division in the family and labour force). Science is a male domain – e.g. the majority of scientists are male, personality traits of scientists are stereotypically male, by today's definition the nature of the physical sciences is 'masculine' (e.g. impersonal, inanimate), and post-hoc definitions of various activities are biased (e.g. working with sewing machines is not seen as evidence of girls' mechanical aptitude but as merely an aid to achieving 'person' goals). This male bias is especially harmful to girls since science subject choices are generally made at an age when students are particularly conscious of gender and are anxious to conform.

Examining the socio-historic context, the social role of science has focused on 2 major concerns – increasing the efficiency of production and social control. Might science be redefined to include more 'feminine' concerns (besides the industrial/military focus) to draw more females to it? And is the increasing interest in attracting more women to science motivated by concern for equality for women or by todays' shortage of scientists/engineers?

50. SHARMA, SHIAM and MEIGHAM, ROLAN (1980) 'Schooling and Sex Roles: the Case of GCE 'O' level Mathematics', *British Journal of Sociology of Education* 1:2, p. 193-205.

This study demonstrates that sex differences in maths performance on O-level exams largely disappears when the variable 'other mathematics-related courses taken' (i.e. physics, geometrical drawing) is controlled for. Girls' and boys' average scores, pass rates and high pass rates were compared for the 12,459 maths exam entrants in 1977 (53% male). Overall boys surpassed girls on all three criteria (e.g. 29% of the girls but 47% of the boys had upper grade passes). However, of those maths students who also took physics (1/3 of the boys, 1/4 of the girls), girls were superior to boys on all three counts (e.g. 54% vs. 46% high pass rate). Boys and girls had similar maths results for students also taking geometrical drawing (with 30 times more males than females doing so).

Thus when a stratified sample was examined (equal numbers of boys and girls with only maths, maths plus physics and maths plus geometrical drawing) sex differences largely disappeared (girls had better average scores, 5.5 vs. 5.2, and more high passes, 36% vs. 27%, while boys had more passes, 63% vs. 67%). The comparisons of the three categories of students within each sex was striking – maths students who also took physics were markedly superior to those who only took maths (e.g. for girls, average scores were 4.1 vs. 6.0, 52% vs. 20% high pass and 80% vs. 48% pass rate – with similar figures for boys) – maths students who also took geometrical drawing fell in between. Within-sex differences were clearly greater than between-sex differences. Thus boys' superior performance on GCE O-levels in maths seems to be attributable to boys' greater maths-related experiences in other non-maths courses.

51. SMITH, PAT (1980) 'Alice and Her Receding Vision of a Perch in the Success Tree', *Times Higher Educational Supplement* 409, 5 Sept., p. 7.

The author reviews material from the book *Alice Through the Microscope* (Birke et al., 1980) which demonstrates the decreasing participation of females in maths/science at each level. In 1977 girls had 39.9% of the O-level maths passes and 27.7% of those in physics; by A-level they gained only 22.9% and 17.9% of the maths and physics passes respectively. In higher education, women earned 3% of the engineering/technology degrees and 18% to 29% of the science degrees (at university and polytechnic). By employment time, women make up only 10% of the scientists and less than 2% of the managers and practicing researchers in science/technology.

Is specialisation for GCE coming precisely at the time of puberty when sex role/academic priorities are questioned with respect to maths/science in particular and career choice/commitment in general? (And in maths/science, there is 'no turning back'). Is the image of science too abstract, academic, impersonal, divorced from social context and requiring high intelligence? Do boys more than girls stick to it anyway because of career pressure, and greater confidence in their abilities? And in employment do women experience greater difficulties such as prejudice, proving oneself, a hostile environment, child-rearing demands in a competitive, time-consuming field?

52. SMITH, STUART (1980) 'Should They be Kept Apart?', *Times Educational Supplement*, 18 July, p. 36.

A secondary school in Stamford set up maths classes so as to compare girls' performances in single-sex vs. mixed-sex classes (using the same teacher in both settings). The situation prior to the experiment was typical: first year girls were initially equal to boys on maths ability tests, but fell considerably behind in maths by the end of the first year on ability tests, asking/answering questions and demonstration of interest in class. This sex difference increased such that by the fourth year boys outnumbered girls by 4 or 5 to 1 in the top 2 maths sets (which prepare students for O-level maths examinations). The few girls in these sets reported feeling uncomfortable in the masculine environment, adopted a deliberately passive role in class, and feared ridicule for wrong answers or 'foolish' questions (no difference was found under female or male teachers).

For the experiment, the top level maths students were assigned to single or mixed-sex classes in the first year. Testing in November of the second year showed single-sex girls' performance was equal to mixed-sex boys' and clearly superior to mixed-sex girls' – this gap increased by February testing. Teacher reports also found girls in single-sex maths classes were livelier, more boisterous, more co-operative and the class had a better working atmosphere.

53. SMITHERS, ALAN and COLLINGS, JOHN (1981) 'Girls Studying Science in the Sixth Form' in A. Kelly (ed) *The Missing Half*, p. 164-179.

This study looked at the relatively few girls who studied physical science (including maths) in the 6th form to examine whether they had distinctive characteristics which might reveal something about the dynamics of science choice. 1900 students from 20 schools in north England were compared – science girls, non-science girls and science boys. The science girls were intellectually and academically superior to other girls as well as science boys on all measures. In temperament, science girls were very similar to science boys (and scientists in general) though different from other girls (e.g. conscientious, tough-minded, controlled). Science and arts students of both sexes agreed that science 6th formers were more intelligent and hardworking, but each group of boys thought their group to be more exciting and attractive. Science girls, however, agreed with arts girls in thinking arts girls were more socially attractive. Nearly all science students planned on going on to degree courses vs. only ½ the other girls – with few planning on teaching.

On the positive side then, girls taking physical sciences were highly intelligent and knew it, had good academic records (in general and in science), and were stable and toughminded. However, unlike boys in science, the girls were somewhat introverted, saw themselves as less feminine/attractive/popular/sociable, and reported more social difficulties. Is this the price they have to pay or is science a refuge for girls who want to be judged on their intellectual rather than social qualities? Does their keen awareness of their high ability over-ride the social pressures against science entry as inappropriate for girls? Or does the rejection of the 'feminine' by choosing science lead them to see themselves as different in other ways as well?

54. STAMP, PEGGY (1979) 'Girls and Mathematics: Parental Variables', *British Journal of Educational Psychology* 49:1, Feb., p. 39-50.

Girls taking A-level mathematics were compared with girls taking A-level French on personality measures (including masculinity/femininity), parental identification, attitudes, and influence, and attitude toward their subject. 299 subjects (and their parents) from 14 schools (single and mixed-sex, comprehensive and grammar) were tested in 1975–76. The mathematics girls were found to be more 'masculine' intellectually (more reserved, emotionally stable, tough-minded, thing-orientated, experimenting and radical) and career-wise (more definite career plans and of a less conventional nature), but more 'feminine' socially (more nurturing, home-related, traditional interests and activities as well as more group dependent) as compared with girls taking French.

Contrary to the assumption that girls in general identify with mothers and girls in maths/science with fathers, no difference between maths and 'French' girls were found; for both groups more girls identified with fathers than mothers. Subject choice was most influenced by 'sex-appropriate' parent (fathers for maths, mothers for French) – though over half of each group reported no parental influence. Parental attitudes and ability also affected subject choice – girls were likely to take a foreign language if their mother liked it – girls were likely to take maths if both mother and father liked it and father was good at it. Girls' attitudes towards their respective subjects, however, were most related to their mothers' attitudes to the subjects. Hence, females' positive maths attitudes are important, even if not relevant to their career, for the part they play in influencing their daughters' attitudes and subject choices in the future.

55. TANNER, R. and TROWN, ANNE (1979) 'Cultural Change and Mathematical Thought', *British Journal of Educational Psychology* 49:3, Nov., p. 239-248.

The mathematical thinking ability (i.e. relational thinking, patterns, generalisations) of three groups of 60 10-13 year olds were compared: Indian/Pakistani/Bangladeshi recent arrivals, those Asian-origin children who had lived in England since birth and white British children. No significant ethnic differences were found. However Asian-origin girls in England since birth were markedly superior to their male counterparts at age 10/11 and marginally superior at 12/13.

56. TAYLOR, J. (1970) 'Sexist Bias in Physics Textbooks', *Physics Education* 4:5, July, p. 277-280.

Three typical physics texts were examined – a Nuffield O-level, a CSE textbook and a general textbook (from 1967, 1970 and 1975). A definite sexist bias was found in the illustrations, diagrams and written texts of all three books on all criteria: disproportionate use of males (including the term 'he'), sex stereotyping (including male-active, female-passive), and the use of 'male' objects/experiences for examples. 'References to females were few (even when the sex of the person was immaterial), references to active females were even fewer and references to females in scientific activities were virtually non-existent'. Besides an overt sex bias, another aspect of the texts which may put girls at a disadvantage is the paucity of references to any person at all (an interest of girls).

57. THOMPSON, N. (1979) 'Sex Differentials in Physics Education', *Physics Education* 14, p. 285-288.

This article examines the sex imbalance in physics for 16+ exams through higher degrees in 1975–76. Two important decision points – middle school subject selection and university entry – are examined using a 1973 DES study and university applications data.

Overall about equal numbers of girls and boys take O-level exams, but in physics about 4 times as many boys as girls apply. This is a more extreme sex ratio than any regular (non-craft) subject, and, unlike other science areas, is not becoming more balanced in recent years (maths 1.4, chemistry 2.1, biology 0.6). The same picture is true for CSE. (The CSE figure may more accurately reflect the position in the schools since O-levels draw 20-25% FE candidates). At A-level the sex imbalance on physics entrants increases to 5:1, though again girls have a slightly higher pass rate than boys. And just as girls have a higher dropout rate from O-level to A-level physics, so too do they in applying to university in physics (a sex ratio of about 8). Beyond that the sex ratios are 6.7 for obtaining a degree in physics, 7.8 for higher degrees and about 20 for doctors degrees.

The sex imbalance is obvious from the first selection of science subjects in middle school. The DES data for science showed that the bias in school course offerings (more pronounced in single-sex schools) correlated with the bias in students' subject choice (worse in mixed-sex schools). However, actual course-taking seemed to result more from student choice than school facilities. However, the choice may not be entirely 'free' – e.g. parent/teacher pressure, restricted earlier specialisation, timetabling and packaging of programmes.

Why do proportionately fewer girls with A-level physics continue in physics at university – where do they go? Dramatic increases in female applicants in medicine and dentistry suggest that these may be their destination. Speculation as to why this occurs questions whether physics (and science in general) is increasingly moving toward the inclusion of technology which may be inimical to feminine interests.

58. WEINER, GABY (1980) 'Sex Differences in Mathematical Performance: A Review of Research and Possible Action', in Rosemary Deem (ed) *Schooling for Women's Work*, London: Routledge and Kegan Paul, p. 76-86.

The author reviews British and American research on cognitive, socialisation, schooling and attitudinal influences on sex differences in maths. (Only British studies are discussed here). Many general studies on sex bias in education have implications for maths. 'Sex' is used to separate children for purely organisational reasons, e.g. on the register, when lining up, for quizzes and games, on assigned tasks. Staffing patterns usually reflect traditional sex roles – primary school teachers are women, later secondary teachers are about equally male and female, head teachers and head masters are overwhelmingly male, support staff are nearly all female. Primary teachers are likely to perceive girls more favourably than boys – more sensible, obedient, hard-working, co-operative, quiet, mature, bright and likeable as opposed to boys being more excitable, talkative, and in need of more supervision and attention. And the sexism in textbooks is well-documented.

On maths in particular, boys report liking it because it's difficult, girls dislike it for the same reason. Maths textbooks exhibit sexism – e.g. the numbers of each sex shown, the types of activities, characteristics and occupations. Prior to the 1975 Sex Discrimination Act there was considerable sex segregation in subjects (by choice, discrimination, channelling) into traditional areas (cooking vs. woodwork, biology vs. physics) as well as unequal allocation of resources to all-girls' and all-boys' schools (e.g. adequate science laboratories). Suggestions include special encouragement of girls by maths/science teachers, drawing sample problems equally from females' experiences, dissemination of information encouraging girls to go into the field, and an active effort to include girls in class.

59. WEINREICH-HASTE, HELEN (1981) 'The Image of Science', in A. Kelly (ed) *The Missing Half*, p. 216-229.

Students' images of science and the scientist are examined. Does the image deter girls from entering science? Does the stereotype fit with reality? The general cultural view is that science is a rational activity where the human/social component is underplayed, aimed at obtaining knowledge to gain control of the environment. Children's view includes both the 'stage scientist' (the mad professor – old, eccentric, physically unattractive) and the 'modern scientist' (what they might grow up to be – pre-occupied with work, lacking social contact). Both have elements of abnormality – very intelligent, socially isolated, lacking social graces. Hence, science is more than a job, it's being a type of person and adopting a lifestyle. For girls, also relevant is the strong masculine image which, when taken with the above, does not fit with female roles expectations (predominantly males, preoccupied with work, not physically attractive, socially isolated, unfeminine). Hence, for girls to aspire to a science career requires strong motivation, independence, a non-traditional attitude towards sex roles and an internal criteria for self judgement.

A study of 13-14 year olds and university students asked them to give their image of the scientist, rate subjects as masculine/feminine, and state why they would/wouldn't want to be/marry a scientist. The stereotypes discussed above were borne out in their responses.

Studies of real scientists and their jobs suggest a gap between the stereotype and the scientist on some dimensions of personality, social/family life and work experience. Also contrary to the stereotype, the process of science is often not objective, detached, purely rational and an individual activity. No doubt there is also a difference between the gifted, elite scientist (which may be closer to what students imagine) and the average scientist (which most aspiring science students will become) in terms of job, time, commitment, need for imagination, etc. In terms of drawing more girls into science, there is a need to convey a more accurate picture of the real scientist/the average scientist and dispel the negative, masculine, abnormal image so prevalent.

60. WHYTE, JUDITH (1981) 'Sex Typing in Schools', in A. Kelly (ed) *The Missing Half*, p. 264-275.

Sex bias in the schools is discussed in general as well as with respect to science in particular concerning hidden curriculum, teacher bias, school/class structure, facilities, careers advice and crafts classes. Specific areas include the following.

Introduce teachers to compensatory teaching strategies for encouraging girls in science classrooms (those currently used are biased towards boys). Discourage sex segregation (of duties, lines, seating, play, etc.) which encourages categorisation of science (as male) as well. Actively encourage girls in science classrooms (where they appear to require and get less attention). Eliminate biased channelling of girls into biology rather than physics/chemistry due to lack of facilities, course packaging, careers advice, scheduling. Begin unbiased careers advice early (before course choices are made), exposing students to a variety of science/technical jobs, pointing out the relevance of science for keeping future opportunities open as well as for even traditional female jobs, and not overemphasizing the difficulty/demands of science/engineering courses/jobs. Girls need to be allowed to and encouraged to take more crafts courses – and a new concept of home crafts is needed to broaden it into a science area.

61. WOOD, ROBERT (1976) 'Sex Differences in Mathematics Attainment at GCE Ordinary Level', *Educational Studies* 2:2, June, p. 141-160.

Not only do more boys than girls take O-level maths, but they tend to do better on the whole and on certain types of questions. This study looks at individual items of the 1973 and 1974 O-level maths exam for a total of 1884 London students from mixed-sex schools. (A sample of 418 girls from girls' schools was also used for separate comparison since they generally do better than girls from co-ed schools).

Boys surpassed girls particularly on items involving scaling, which is in essence proportionality (important in probabilities). These sex differences persisted when comparison was made with girls from single sex schools. Girls outperformed boys on modern maths items (e.g. sets, matrices, number lines). Individual schools were examined to see if sex differences persisted across schools – in some cases the difference vanished and even reversed. But even taking school into account, boys still surpassed girls on scaling/measurement problems, probability and space-time relationships.

On the free response questions where some choice of questions was allowed, sex differences in preference and performance were also found. Girls chose more modern maths questions (though they did not do better than boys on these), and boys were much more likely to choose probability and geometry questions.

Various theories for these differences were discussed. The motivation hypothesis suggests that girls don't like certain types of topics (male-oriented, un-interesting) so spend less time studying them, resulting in poorer performance. The female dependency hypothesis suggests girls will stick to secure, teacher-approved methods resulting in their doing well on rote learning, but not on problem solving questions. The stage vs. holistic approach hypothesis suggests that girls break problems into multiple stages resulting in a greater number of places for failure especially under time limits (with less time for plausibility check). The spatial visualization hypothesis (with a genetic basis) cannot be ruled out. The female menstruation hypothesis was ruled out as unlikely. Lastly, the development theory was considered – girls may take longer than boys to attain the formal operations stage (dependent on available structures and experiences).

62. WOOD, ROBERT (1977) 'Cable's Comparison Factor: Is This Where Girls' Trouble Starts?', *Maths in School* 6:4, Sept., p. 18-21.

The maths O-level exams (1973–74) of 1884 London students were examined for sex differences in the 60 multiple choice items. Boys outperformed girls on all but 7 of the items – all 7 being modern maths (e.g. Venn diagrams, matrices). The areas with the largest sex difference favouring boys involved aspects of scaling/proportionality. In an earlier article the author hypothesized that this may be due to girls lagging behind boys in reaching Piaget's formal operation state (e.g. abstract thinking). He now attributes this to girls' greater difficulty with the 'comparison factor' (pointed out by Mr. Cable – i.e. being able to see how one quality compares with another, as with fractions and proportions). A second area where girls don't do as well is solid geometry which requires spatial visualization. Might the two be connected? Is dealing with fractions and proportions – the comparison factor – really part of spatial ability, i.e. being able to perceive, recognise and assimilate patterns (also called for in problem solving)?

On the other hand, girls do better in recognition and classification problems (supplying definitions, applying techniques) – things most susceptible to drilling (rote learning). Girls' greater conformity and dependence perhaps encourages them to keep to methods they're confident in, be cautious, avoid being wrong, reproduce techniques they're taught and use teacher approved methods.

Studies in Science Education 9 (1982), 109-146

Demonstration versus Small Group Practical Work in Science Education. A critical review of studies since 1900

R. M. GARRETT
School of Education, University of Bristol

I. F. ROBERTS
Department of Education, University of Keele

INTRODUCTION

Whilst there have been numerous research studies into the relative merits of teacher demonstration and small group practical work, in general they are widely scattered and irregularly distributed, not only within the literature but also in terms of chronology, country of origin and the educational variables investigated. Such factors make the extraction of any underlying trends difficult and, as Keiser (1933) noted, the matter is further complicated by a confusion with respect to the definitions of terms employed.

It is important therefore to attempt to clarify what we mean by 'teacher demonstration' and 'small group' work. In practice both terms are open to wide interpretation, are used in various contexts and there is often considerable uncertainty, not only between studies but also within the same investigation, as to what is actually being compared. For example, small group work is often linked to 'discovery' or heuristic learning, while demonstration tends to be regarded as part-and-parcel of 'reception' or expository teaching, these being further examples of terms which are interpreted in numerous ways. It is necessary, therefore, for the distinction between broad instructional procedures such as reception and discovery learning and the somewhat more specific practices of demonstration and small group work to be precisely recognised and for a generally accepted terminology to be adopted. Following Garrett (1978), we shall employ the terms EXPOSITORY and EXPLORATORY as being more meaningful than 'reception' and 'discovery' because they reflect more precisely the teacher activity at one end and the pupils' classroom behaviour at the other, while not being clouded by overtones of any actual learning processes that may, or may not, be taking place during these activities.

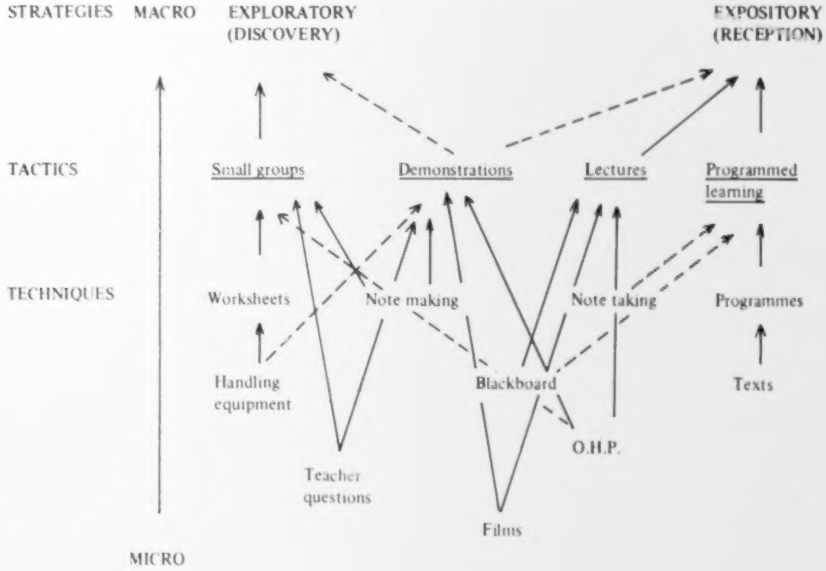
It is also necessary to make a clear distinction between such broad educational activities as exploratory and expository behaviour and the more specific practices of demonstration and small group work. Whilst Garrett (1978) distinguishes between the terms 'methods' and 'techniques', Galton (1979) and others, use the terms 'strategies' and 'tactics'. To prevent a proliferation of terminology the latter have been adopted, where appropriate, in this present paper.

The term STRATEGY is seen as describing the highly complex instructional procedures which reflect the overall approach employed by the teacher while TACTICS are less complex procedures used within the primary strategy. Contained within a TACTIC is a set of TECHNIQUES, which, being the least complex of the activities employed by the teacher, may be regarded as the fundamental or 'atomic' units of any teaching situation.

Figure 1 attempts to show some of the possible relationships between strategies, tactics and techniques. We note from the comparison of the two contrasting *strategies* of exploration and exposition that there is a tendency for clusters of *techniques* to be more closely associated with certain *tactics*. Therefore a strategy is characterised by the frequency of the tactics clusters, which in turn are characterised by the techniques.

Additionally the positioning of demonstration between the exploratory and expository strategies illustrates how spurious investigations of its effectiveness have arisen. Clearly whilst it may be used in the context of one strategy or the other, the small group tactic will normally be employed in the exploratory dimen-

Figure 1. Relationships between strategies, tactics and techniques.


STRATEGIES
MACRO
EXPLORATORY (DISCOVERY)
EXPOSITORY (RECEPTION)
TACTICS
Small groups
Demonstrations
Lectures
Programmed learning
TECHNIQUES
Worksheets
Note making
Note taking
Programmes
Handling equipment
Blackboard
Texts
O.H.P.
Teacher questions
Films
MICRO

sion. Such considerations will be taken into account when appraising the various studies investigated.

However, even within such careful attempts to define strategy, further semantic problems still remain. The researcher must also be clear as to what is meant by the terms demonstration and small group and in particular what distinguishes one from another. In this context Bernstein's concept of framing is useful because it helps to distinguish between these two tactics. He defines a frame as being the form in which knowledge is transmitted and received: 'frame refers to the degree of control teacher and pupil possess over the selection, organisation and pacing of the knowledge transmitted and received in the pedagogical relationship'. (Bernstein 1971 p. 50)

Thus if one considers a series of teaching units,* be it a topic or a course of work, then the overall selection, organisation and pacing of these units is a function of the ***strategies*** employed while the framing of the units themselves is a function of the techniques. The difference therefore between demonstration and small group tactics lies in the relative strength of the teacher and pupil framing. Thus demonstration tactics are strongly teacher framed while small group tactics will be more strongly pupil framed, at least in the organisation and pacing of the unit, if not in the selection of its content.

Finally the term 'small group' must be defined. Most workers (e.g. Mukerji (1940), Young (1949), Kruglak (1952a) and Kruglak & Goodwin (1953)) seem to assume that 2-5 pupils is the optimum size of a group. Additionally the differences between small groups and individuals will also be included in our review as many workers studied the individual working alone in their overall experiment.

It is interesting to note that the questions preoccupying some educationalists during the first two decades of this century are still with us as we enter the last twenty years of the 20th century. Wiley (1918) summarises the problems isolated by Spear (1915) and, as most of the questions raised have a very familar ring, it is worth quoting some of them here. He asks:

> 'what would be the correct amount of time to spend upon chemistry and how should this time be distributed? . . . how can we best promote dexterity in the manipulation of apparatus? Does observation gained in chemistry increase accuracy of observation in the ordinary circumstances of life? Should careful directions be given to students for observations or should they be free to observe what they will? . . . Should experiments be chosen simply to illustrate a point or to correlate the new facts with those previously learned? . . . In logical reasoning should we insist upon the student holding to conclusions limited to the data at hand or generalising beyond these data? How are we to teach the pupil to test his premise? Should the student know beforehand the purpose of his experiment or should the results determine the purpose? . . . (p. 181-182)

---

* Bernstein defines a unit as any specific time period devoted to any particular content or curriculum.

All of these problems and others, Spear maintained, should be investigated by experiment. If the field of endeavour under consideration in this particular paper is a typical example of such investigations, then it is probably true to say that considerable effort has been put into answering these questions but, for one reason or other, we are not much nearer to discovering the answers. It may be that these are not the sort of questions we should be asking and it could be argued that these are questions of a rather minor nature and do not add considerably to our knowledge about the overall problems of teaching and learning. This is a point that will be taken up more fully when we come to discuss the whole value of such studies. Meanwhile, however, it would seem that much of what we do in science education is still largely based upon the personal and subjective opinions of text writers and curriculum development teams, irrespective of the experimental findings that may be available. This is particularly so in the area of science practical class tactics and techniques.

The answer to many of the problems posed by Spear (1915) is currently felt to lie in exploratory, practical based science classes and it is probably true to say that many science teachers have come, wrongly we feel, to regard demonstration teaching as predominantly part of the expository strategy which, with the upsurge of heuristics in recent years, has come to be frowned upon. On the other hand it is also the case that there is still a feeling that demonstration is sometimes both necessary and desirable. The reasons are firstly, cheapness (currently an important consideration), secondly, an acceptance of the premise that where dangerous or complex procedures are called for, it is obviously better for the teacher to carry out the experiment, and finally, that it allows pupils to see equipment being handled properly.

Newbury (1965) discusses all these points and states that demonstration and small group work are complementary, suggesting however that a larger proportion of demonstration classes should be given to girls. Where he obtains the evidence to back up these views he does not say. While he seems to champion the demonstration class and recognises that research reports from the USA support the contention that it is at least as valuable as small group work, he does eventually place it quite firmly within the expository strategy when he concludes: 'The individual method is essential for the discovery or rediscovery, when the result is still unknown to the pupils, while demonstration method concentrates on emphasising broad principles and on verifying the result of an experiment'. (p. 138-9)

Heafford (1965) states the usual dogma surrounding small group practical work: 'Few English (British) teachers will dispute the extreme importance of practical work carried out in the laboratory by pupils. Apart from the educational experience involved in experiment, something genuine learnt as a result of an experiment performed by the pupil is always more firmly understood and remembered than something which is merely demonstrated to him by the teacher or which is told or read about' (p. 88). However, like Newbury, his argument is again backed up with no hard evidence and other workers question that the right sort of learning takes place under these circumstances. Galperin (1953) cites the work of Marozova (unfortunately without giving a full reference) who studied pre-school Russian children of 7-8 years of age. It might be assumed that these pupils would be at some sort of concrete level of cognitive development and therefore largely dependent upon the physical handling of equipment in the learning situation, but it was found that those who performed no actions, merely following, in an active manner, a teacher who carried out the manipulation of materials, were superior in knowledge to those who had carried out the manipulation for themselves. The explanation offered by Galperin (1953) is that the active demonstration method frees pupils from performing physical tasks and leaves them unfettered and able to attend to the relevance of what is being shown to them. One is inclined to ask, is it possible that handling of equipment is good training only for the handling of equipment and that, in consequence, underlying information which such manipulation might reveal is lost?

In a more recent review of opinions on this subject Connell (1971) draws the attention of the reader to previous research, though without quoting any of it, and states that, in general, this work has failed to establish the superiority of individual work over demonstration. He concludes: 'It is surprising that, on a matter affecting so vitally the effectiveness, the scope and the cost of science teaching, there should be not merely a conflict of unsubstantiated opinions but an absence of any attempt at serious examination' (p. 701).

As far as the United Kingdom and most other areas of the world are concerned this is fair comment, but considerable work has been carried out in the USA, although its value is often questionable and sometimes the findings would seem to be rather trivial.

Much of the lack of faith in research findings may not stem entirely from a criticism of research methods. The conclusions arrived at by many reviewers may also have had adverse effects and discouraged prospective researchers. All too often the conclusions reached have been of the opinion that most research studies have been fruitless, having failed to demonstrate any relationships between the variables investigated. While we leave until later in this paper a discussion of the implications of this on research design and the current shift in emphasis that may have arisen partially from the disillusionment created by this situation, we must at this point address ourselves to the various methods of reviewing and synthesizing findings. In particular we consider the challenge that has been made to the pessimistic view that much traditional research in this area has yielded little of worth.

It has been argued by some (e.g. Gage (1978)) that this negative view of research taken by reviewers had led to a great deal of useful data being discarded. Whilst most reviewers have concentrated on the problems of experimental design and the use, or lack, of adequate statistical treatment of data, it is argued that Type II errors are committed, i.e. rejection of hypotheses when in fact they should be accepted. Some workers such as Hedges (1978) claim that a failure to test even for such, hitherto unquestioned, statistical assumptions as normality and homogeneity of variance may not necessarily invalidate a study. Glass (1976) claims that studies with 'half a dozen design and analysis flaws may still be valid'. Such suggestions would seem to strike at the heart of statistical and experimental design theory. To espouse such a view would be to encourage the production of substandard studies which would seriously impair the reputation of educational research and may yield dangerously misleading findings.

Therefore we argue for the adoption of as rigorous an approach as possible towards experimental design and for the use of the most appropriate statistical procedures at all times. Indeed the use of such procedures will be regarded as an important criterion in the judgement of studies in this review. However, it is probably true to say that no investigation will be totally free from criticism of some sort and if there is some evidence to indicate that the difference between 'poor' and 'well-designed' is small (Glass 1976) then one is hesitant about squandering evidence simply because individual studies have produced inconclusive findings or do not conform to some 'ideal' of experimental procedure. What is required is some balance between the possible extremes of accepting everything or rejecting all but the perfect. Having subjected studies to some sort of screening whereby the most grossly unreliable have been eliminated, it would then be useful if some summation of findings that remain could be made.

Gage (1978) has argued that because the learning process is complex, one can hardly expect individual studies of the effects of a single teaching behaviour (technique as defined above) on learning per se to yield anything but statistically insignificant results. Therefore, if Type II errors are not to be made, some way of synthesising the results of these studies must be sought. Dubin and Taveggia (1968) and McKeachie and Kulik (1975) simply resorted to a counting of results, ignoring statistical significances, and found consistent outcomes. Gage (1978) has, quite rightly, suggested that this mere vote counting can be improved upon and has attempted to show that individual study findings can be converted into chi-squared values which in turn can be summed and the probability of this sum against a null hypothesis can be estimated. However, one is hesitant about adopting such a technique and applying it to the cluster of studies presently under review, particularly in the light of the poor conceptualisation of the problems and the lack of agreement as to the definitions and what is actually being investigated in the later, more statistically reliable, findings.

Apart from the regular digests of educational research* which include some of the major papers in this field, there have been occasional reviews of the literature (Downing 1925, Riedel 1927, Croxton 1929, Good 1930, Payne 1932, Stuit and Englehart 1932, Keiser 1933, Cunningham 1946, Kruglak and Wall 1959). However each of these is incomplete in its coverage of the literature or is limited in its treatment (e.g. Kruglak and Wall 1959 deal with research into physics teaching only) and in the twenty years since this last review much fresh work has been carried out. The purpose of the present review is therefore to

---

* Periodic digests have been produced by Curtis (1929, 1931 and 1936) Boenig (1969), Swift (1969) and Lawler (1970).

i. fill in the gaps of the previous reviewers
ii. gather all the data into one paper, and
iii. focus interest and future research on this area of science teaching.

REVIEW OF THE RESEARCH

This section will consider the work in four main phases: up to 1926, 1926-1946, 1946-1960 and from 1960 to the present time. These divisions have been selected in that they broadly reflect progressive stages with respect to the development of the investigational techniques which were used.

Pre 1926 is seen as an introductory phase; 1926-46 relates to a period during which the basic ideas of experimental design were being explored; 1946-1960 relates to a period when the researches were based on much improved experimental designs and involved progressively more statistical analysis; and post 1960 may be described as the curriculum development era. The research findings will be judged in the light of the following criteria:

i. The experimental design used.
ii. The statistical techniques and conclusions produced.
iii. The investigational tools employed.
iv. The purity and consistency of the strategies and tactics employed, as defined above.

Other workers have produced much more detailed lists of criteria. Keiser (1933) in particular has attempted to rank studies from scores accorded to them, but, as we have already noted, he recognised the extreme difficulty of equating the wide interpretations between workers of even the simplest concepts. Cunningham (1946) also notes that, despite his attempts to be as objective as possible, many of Keiser's ratings are open to serious criticism. Indeed until some agreement as to basic definitions etc. has been reached the summation of findings from different sources will always be difficult and open to doubt.

It is hoped that the discussion in this paper will, in some way, contribute towards an accepted set of standard definitions thus making comparisons between future investigations more useful.

A. PHASE I: 1900-1926

Gilbert (1910), Mayman (1912) and Wiley (1918) would seem to represent the first significant attempts to evaluate teaching procedures in science, although the investigations of the first two workers do not seem to correspond exactly to the lecture demonstration and small group work approaches as generally understood. Apparently some attempts were made to standardise tests and their marking but these are not very convincing. The statistical treatment of the results was merely a

Table 1. Summary of the major Phase I studies, 1900-1926

AUTHOR COUNTRY & SUBJECT	SAMPLE AND AGE GROUP	DESIGN OF INVESTIGATION	STATISTICS	INSTRUMENTS	PURITY OF STRATEGY	RESULTS	COMMENTS
Gilbert (1910) USA Biology	N=17+15=32 – Wide age range	Poor; no pre-testing; no matching.	Comparison of means.	Essay type. No pilot testing.	Different strategies	Applied approach superior w.r.t. immediate recall	Not strictly demonstration and small group
Mayman (1912) USA	–	Ranked by Keisar as 'intermediate'	–	–	Good	–	–
Wiley (1918) USA Chemistry	N=3x8=24 – 16-20 yrs	Physics pre-test; doubtful quality; some	Comparison of total scores and means	Essay type	Good	Text-book approach w.r.t. immediate and delayed recall (one m)	Other factors investigated; sex diffs. and individuals
Phillips (1920) USA Physics	'Pupils'	–	Comparison of % scores	–	–	Demo. superior w.r.t. delayed recall (3 m)	Poorly reported, dubious value
Cunningham (1920) USA Botany	N=3x8=24	No matched groups	Comparison of means	–	Good	Demo. superior w.r.t. delayed recall (1 m)	
Cooprider (a) (1922) USA Biology	N=3x14=42	Groups equated using standard tests. Not matched pairs	Comparison of means	Write-up of expts. with objective marking	Good	Demo. superior w.r.t. immediate recall, 'observation'/'manipulation'/ reasoning	Also looked at oral & written instructions. Different learning outcomes reduced to one score
Kiebler and Woody (1923) USA Physics	'Pupils'	Groups equated using standard tests. Rotation of groups	Comparison of averages	Objective: completion, T/F, matching, best answer	Difference in strategies	Demo. superior w.r.t. immediate recall & problem solving. Lab. superior w.r.t. delayed recall (2 wks)	Important study; reimprovement in design
Cooprider (b) (1923) USA Biology	N=4x17=68	Groups equated using standard test	Comparison of means	–	Common expository strategy	Demo. superior w.r.t. immediate recall. Lab superior w.r.t. delayed recall (1 m)	Oral & written instructions also investigated. Oral superior

Cunningham (1924) USA Botany	N=2x10=20 students	Rotation technique: no matching of groups	Comparison of means		Common exploratory strategy	Demo. superior w.r.t. immediate recall. Lab superior w.r.t. delayed recall (3 m)	Results similar for observation, problem solving and reasoning
Pruitt (1925) USA Chemistry	N=3x20=60 'Pupils'	Groups equated on Otis Graded Intelligence Test. Not homogeneous for age	Some consid. of S.D. & coeff. of correlation	Immediate test: brief answer, 'thinking'. Delayed test 25 T/F	Seems to be good	Demo. superior w.r.t. immediate recall. Lab superior w.r.t. delayed recall (1 m)	Boys/Girls, dull/bright also investigated
Anibel (1926) (2 studies) USA Chemistry	a) N=2x23=46 b) N=2x17=34 'Pupils'	Groups matched. Army Alpha Test & Otis Group Test. Experimental/control groups	Comparison of means	One word answer test: no details	Exploratory in both groups	Demo. superior w.r.t. immediate recall (both invests.). Lab superior w.r.t. delayed recall (15 m) (invest b). No diffs between tactics w.r.t. delayed (?) (invest a).	Very small group of 'bright' pupils preferred lecture approach. Lecture 2/3 quicker and 1/15 cost
Ewing (1926) USA	N=8x35=270 'Pupils'	Stanford Achievement Test, but arbitrary grouping. McCall rotation	Comparison of means	Four objective & essay tests: not piloted	Same strategies with both groups	Demo. superior w.r.t. immediate recall. Lab superior w.r.t. delayed recall (2 wks)	
Walter (1926) USA Physics	N=4x20=80 'Pupils'	I.Q. of experimental and control groups; markedly diff.	Comparison of means	–	Poor (see comments)	Demo. superior w.r.t. immediate and delayed (?) recall.	Time saved by demo. given as extra drill.

comparison of average scores between the different experimental groups and on the basis of such data the only valid comment is that of Wiley (1918) himself: 'there is not so great a difference as is ordinarily supposed in the values of the three methods . . . as far as the imparting of knowledge is concerned' (p.197).

The work of Phillips (1920), Cunningham (1920 a and b), Caldwell (1921) and Hunter (1922 and 1923) also seems to suffer from similar shortcomings, and of those seen by the authors, Phillip's report is particularly unhelpful in that he does not indicate sample size, number of teachers, age of pupils, the duration of the experiment or the type and nature of the tests employed. Again, in all these studies analysis of the data is scant, with only a comparison of average scores being offered.

The fact that all these aspects of design, testing and statistical analysis are so poor means that no confidence can be placed in any of these findings. It is probably fair to say that these studies do not contribute to the overall accumulation of data in the field and, despite any claims the authors may make for their work, there is no evidence to indicate any superiority of one teaching tactic over the other.

Cooprider's studies (1922 and 1923) show some improvement of design. In his first investigation of the relative values of oral and written instructions together with demonstration and small group work, he attempted to divide his student sample into homogeneous groups on the basis of results from standardised tests (The Chicago Group Intelligence Test). However his total sample of 42 pupils was very small, a fault he corrected to some extent in his second study. He also attempted to produce an objective system of test marking, but this was not successful. Both of these investigations produced similar findings, though the difference in mean scores was so slight that, had sound statistical techniques been used to estimate the significance, it is probable that no meaningful differences would have been detected.

Possibly a turning point in the refinement of experimental techniques comes with the study made by Keibler and Woody (1923). Their experimental groups were equated on the basis of a pretest intelligence score and treatment groups were rotated, thus obviating the need for a separate control group. This technique has been attributed to McCall (1923) and variations of it were also used by Cunningham (1920 a and b) and Ewing (1926). A further step towards improved experimental design was made by Pruitt (1925) and Anibel (1926). They used the more usual method of experimental and control group arrangement but in so doing Anibel, in particular, introduced the use of a good sized sample of matched-pairs, based on a battery of standarised tests such as the Army Alpha Test Form B and a shortened Otis Group Test Form B together with other attainment tests.

Kiebler and Woody (1923) were also the first workers to attempt to investigate the effects of the two tactics on anything other than simple factual recall. They attempted to investigate their effects on pupils' abilities to apply principles and techniques to new problems. However, the construction of tests to do this was not reported in any detail and it is doubtful if they were of any real value.

Again the Kiebler and Woody study was remarkable in that it would appear to be the first time that the true objective-test type of question emerged in this series of investigations. The question types produced by Pruitt (1925) were supposed to have been constructed to require 'brief answers and a maximum of thinking' but their validity and objectivity must be open to doubt. Pruitt's delayed retention tests however did move some way towards marker objectivity in that these consisted of 25 true/false items. Anibel (1926) gives the impression that he used objective type tests with only one word answers being required, but it is in the study of Ewing (1926) that true/false and multiple choice tests of any real consequence were devised. However, he still relied heavily on essay type questions to test for what he termed principles, concepts, definitions and applications.

All the studies of this first phase suffered badly from many weaknesses and the gaps in Table I attest to the failure of workers to report vital information such as sample size, sampling techniques employed, selection of teachers, etc., but the main overall failing of the workers of the period was their inability to recognise the need to subject their findings to any statistical treatment. The only study worth mentioning in this respect is that of Pruitt (1925).

A certain degree of statistical sophistication was used, such as a consideration of the standard deviation of the scores and a computation of the coefficient of correlation between retention and intelligence scores for all groups. Pruitt's (1925) findings were statistically inconclusive and therefore no real differences were demonstrated between the two tactics for immediate recall. Similarly no differences were detected in the effectiveness of the two tactics for either boys or girls or for dull or bright pupils. He claimed that there was a 'marked' superiority of individual work for long term retention but this must be considered tentative. His findings did perhaps show that the demonstration tactics tended to make the groups homogeneous (small Standard Deviation) while scores from the individual groups had a wider range (large S.D.) indicating that students could display their individual differences when exposed to that tactic.

It is interesting to note that in most of the investigations so far cited there was a clear perception of the need to keep the teaching strategies pure and, as Downing (1925) comments: 'In the case of laboratory work the pupils were given their instructions either orally or in writing and proceed with the work without assistance from the teacher. In the teacher-demonstration method, the instructor as he performs the experiment, uses the same language found in the laboratory instructions . . . He avoids any instructions by direct exposition . . . In other words, the attempt is made to keep all elements of the experiment identical except the one variable – in the lecture-demonstration method the experiments are performed by the instructor; in the laboratory method, by the pupil' (p.691). It is unfortunate that while all other aspects of investigational techniques have become refined over the years this particular issue of purity of strategies has not been refined and indeed at times it has been almost ignored.

There would seem to be a natural break at this point, with this early work now being largely of historical interest showing how research designs were becoming more refined and characterised, as might be expected, by the limited range of pupil behaviours and educational areas covered. However there is some superficial indication that demonstration tactics were superior to small group work for short term retention while the reverse was true for longer term recall. But bearing in mind the previous comments, the researches cannot be afforded any importance as reliable sources of data and it is probably also true to say that no significant results were found.

Discussion at the time, however, centred around the importance of laboratory classwork as compared with text-book recitation work (Bowers 1924) rather than with the type of laboratory class to be provided. Although it would seem that small group work was favoured among the text-book writers, Bowers (1924) quotes a survey by Hopkins (no date) which showed that of ten popular elementary texts in the USA, nine of the ten favoured a practical approach with pupils carrying out the experiments. As Bowers says, despite this opinion 'the question still remains, is this the kind of chemistry to teach a beginner?' What is clear is that then, as now, teaching strategies and tactics were advocated on the grounds of personal opinion and conviction with little regard for the available experimental evidence.

Possibly the most important observation arising from this period was that of Wiley (1918) and particularly Kiebler and Woody (1923) when they noted the need to identify and classify the nature of the experiments themselves before investigating the most effective tactics to be used with them.

Table 2: Summary of the main findings of the Phase I studies

Results Learning Outcome	Demonstration Favoured	Small Groups Favoured	No Differences Favoured
Immediate recall	11	0	0
Delayed recall	2	8	1

N.B. As no statistical treatment of the above results was carried out there is no attempt to indicate levels of confidence

B. PHASE II 1926-1946

Of the 31 investigations traced from this second phase, most show some improvement in one or more of the areas under consideration. It is proposed therefore to take each of the four criteria (see p. 115) in turn and explore the overall movement towards improvement as revealed by Table 3.

Table 3. Summary of Phase II studies, 1926-1946

AUTHOR COUNTRY SUBJECT	SAMPLE AND AGE GROUP	DESIGN OF INVESTIGATION	STATISTICS	INSTRUMENTS	PURITY OF STRATEGY	RESULTS	COMMENTS
Carpinter (1926) USA Chemistry	N=1,500 'Pupils'	Modified McCall's Rotation. No matching of groups	Critical ratio	Multiple choice tests; rigorous construction	Poor	No diffs. between tactics w.r.t. immediate recall. Individualised work superior w.r.t. thinking	Learning outcomes not tested separately
Knox (1927) USA Chemistry	N=42+43=85 'Pupils'	4 classes equated using Miller Mental Test. Two teachers. No control or rotation	Kelley's sigma scores, correlations. No tests of significance	Mixed objective & miscellaneous tests. No piloting(?)	Fair	Demo. superior w.r.t. immediate, delayed recall (3 wks) and application	'Inferior' 'Superior' pupils compared. Time factor different in demo.
Nash & Phillips (1927) USA Chemistry	N=15+15+15 =45 'Pupils'	3 groups matched using Miller Mental test. 2 experimental, one control group. Pre and post tests	% gains and S.D.s compared. Rank changes considered: no stats.	Mixed objective tests. Some evidence of piloting	Poor	Demo. superior w.r.t. immediate recall (?)	Some attempt to look at individual pupils
Dyer (1927) USA Physics	N=49+63=112 'Pupils'	Group matching poor. Rotation of groups. Three lessons only	Comparison of means & medians	No pre-testing. Suspect	Poor	Demo. superior w.r.t. immediate recall & realizations'. No difference between tactics w.r.t. delayed recall (8 m)	Low 'mentality' pupils omitted
Pugh (1927) USA Chemistry	N=42+28=70 'Pupils'	No control or rotation	Comparison of %s only	18 tests. No details, no piloting (?)	–	Demo. superior w.r.t. immediate & delayed recall (2 & 20 wk)	Boys only. Poorly reported. Mastery, resourcefulness and application also tested

Continued overleaf...

Table 3. Summary of Phase II studies, 1926-1946 (continued)

AUTHOR COUNTRY SUBJECT	SAMPLE AND AGE GROUP	DESIGN OF INVESTIGATION	STATISTICS	INSTRUMENTS	PURITY OF STRATEGY	RESULTS	COMMENTS
Horton (1928) USA Chemistry	N=117 N= 43 N=345	Matched groups using Regent's Biology Test. Rotation technique. Good design	Critical ratio and statistical significance used	Test piloted. Validity and reliability measured	Strategy pure	Lab superior (not signif.) w.r.t. immediate recall. Lab superior (stat sig) w.r.t. manipulative skills	Although chemical studies, Biology Test used. Very important study (see text for fuller details)
Wilkinson (1928) USA	N=25+16=41 Pupils 15-19 yrs	No matched groups. 4 experiments only. No controls, no rotation	McCall's 'experimental' coefficient	No information available	Poor	Lab superior w.r.t. immediate and delayed recall (4 m)	Time saving factor with demonstration not significant. With complex apparatus or difficult concepts demonstration favoured
Johnson (1928) USA Biology	1st expt. N=3x11 =33 pupils 2nd expt. N=17+17+16 =50 Students	Matched groups using Terman Group Intelligence Test (TGIT) Rotation technique. All groups performed 8 exercises using three tactics	Critical ratio and statistical significance used	Objective Tests and diagrams used. No reliability and validity	Good. discussion in indiv. banned	No significant diffs. between tactics w.r.t. immediate and delayed recall	Demo. individual & small groups studied. Demo. superior in 5 out of 6 experiments
Erikson (1929) USA Chemistry	N=2x23=46 Students	Matched groups using Otis Intell. Test. Mod. rotation	Comparison of means. Pearson Product Moment (rankings)	Immediate & delayed tests different	Fair	Demo. superior w.r.t. immediate & delayed recall (1 m)	All differences could be explained by differences in tests
Shore (1929) USA Physics	108 teacher 2 schools Pupils	Heat taught by demonstration. Mechanics by laboratory work. Matched groups using TGIT	Comparison of %	Immediate recall-test pretested. Standard Iowa test for delayed	Open to Criticism	No diffs. between tactics w.r.t. immediate recall. Demo. superior w.r.t. delayed recall (3 m)	Poorly reported. Boys/Girls of high, average & low intelligence also studied

Van Horne (1929) USA Chemistry	N=4x16=64 13-20 yrs	Matched groups using TGIT & school assessments 2x7 standard expts. in rotation	Critical ratio. Tests of significance	Objective type designed for retention and 'ability to think' Some tests used by Carpinter 1926	Consistent exploratory strategy	Demo. superior w.r.t. immediate recall. (Not stat. sig.) No diffs. between tactics w.r.t. delayed recall (10-13 wks)	Saving of time – 20% and money, 90% in demonstration. Intelligence diffs also studied
Brasure (1929) USA Physics	N=2x20=40	Matched groups using TGIT & tests on previous science work	Critical ratio	Same pre-post – and delayed test. No details	Insufficient information	Lab superior w.r.t. immediate recall. (not stat.sig.) Demo. superior w.r.t. delayed recall (6 wks). Stat. sig.	Too poorly reported to judge outcome effectively
Scott (1929) USA General Science	N=36 12-19 yrs	Matched groups using Otis self administered Test	Test of significance	Not reported	No report	No sig. diffs. between tactics w.r.t. immediate recall	Very poorly reported
De Jarnett (1929) USA Biology	N=2x19=38 15-19 yrs	Matched pairs using 5 standard tests including TGIT Biology & reading. No rotation. No controls	Critical ratio & 'correlation' co-effic.	Blaisdale test Bio- as part of pre and all post-test	Poorly reported	Demo. superior with low ability students w.r.t. immediate (?) recall	Upper & Lower intelligence bands and boys/girls investigated
Walter (1930) USA Physics	?	Rotation; 2 expts. only by each of 3 tactics	No details	Test of 'ability to think' 'observ.' and 'remember'	Poor	Individual work (no manual) superior w.r.t. immediate recall	Factors investigated/demo. with manual/ without manual. 50% time saving with demo.
Payne (1932) USA Chemistry	N=299 in 4 colleges 5 teachers 'Students'	Paired groups using 5 standard tests	Critical ratio	Batteries of standard & non-standard tests	(see comments)	Demo. superior for less able w.r.t. immediate (?) recall	The demonstration was used only as introductory device with expmtl. group

Table 3. Summary of Phase II studies, 1926-1946 (continued)

AUTHOR COUNTRY SUBJECT	SAMPLE AND AGE GROUP	DESIGN OF INVESTIGATION	STATISTICS	INSTRUMENTS	PURITY OF STRATEGY	RESULTS	COMMENTS
Hix (1933) USA Physics	N=2x30=60 Pupils	Division of sample not recorded. Duration 2 yrs. No control group or rotation	Critical ratio	Series of pre & post-tests (same as tests used before & after). Reliability and validity (see comments)	Poor; diff. strategies	Demo. superior w.r.t. distinguishing between fact/fiction. No diffs. between tactics w.r.t. immediate recall. Lab superior (signif) w.r.t. skills	Reliability of all tests happened to be 82!
Fountain (1934) Physics	Pupils	Possible TGIT used to match groups	Comparison of means	–	Poor; different strategies	Lab 1st Superior w.r.t. immediate & delayed (?) recall	Position of lab. work in normal demonstration
Gerberich & Roberds (1934) USA Physics	Two groups N=6+7=13 Students	Treatment/control groups but not comparable at start	Test analysis good but comparison of means for main data	Pre-tests used Post-tests objt. of aptitude & achievement. Reliability & validity good	Different expts. for both groups: sig. difference in strategies	No diff. between tactics w.r.t. immediate recall	Certain degree of lecture demonstration part of both tactics. Considering size-poor, use of case study interesting
Duel (1937) USA Physics	N=595 Students	Matched groups. No rotation. No controls	Significance mentioned, statistics used, not named	Objective tests Reliability & validity good; plus Stanford Science Aptitude test and final grades	Insufficient information	No diffs. between tactics w.r.t. immediate recall	Also studied – understanding, science aptitude, manipulative skills & transfer
White (1943) USA Engineering	N=2x75=150 Students	Matched groups using Thurston Mental Test	Chi squares and tests of significance	–	–	Lab superior w.r.t. immediate recall & skills. No diffs. between tactics w.r.t. delayed recall (?)	No differences found between students of different abilities

Note: w.r.t. = with respect to

The first point of note is that all the studies, as in the first phase, came from the USA and that most were in the fields of chemistry (13 studies) and physics (10 studies). Only three involved biology classes; the areas of general science and engineering provided one each and two were unclassified. At the time covered by this phase, chemistry and physics were enjoying particular popularity; experimental inquiry was important and was bringing about a more fundamental understanding of these subjects. Consequently it is possible that teachers of physics and chemistry were inspired to employ the techniques that were making their own science so successful to the problems of teaching those subjects. Biology on the other hand was still paving the way for its experimental phase and was largely dominated by collecting, describing, classifying and nature study attitudes – particularly in schools – and teachers of this subject tended not to explore their teaching in a more scientific way, using the inquiring experimental approach of their physical science colleagues. No pattern favouring, or otherwise, the two tactics could be found between the different subjects being used.

The majority of the studies under consideration (15) were carried out in schools. Of others which indicated the ages of the subjects, six were carried out in universities or colleges with homogeneous age groups. This distribution may have been due to the ease with which large numbers of pupils could be acquired for respectable samples, but if this was so, far too many studies employed very small samples. However it may be that these studies were carried out by teachers, registered for higher degrees, who used their own classes as the most accessible sample. Certainly this series of investigations does display a 'one-off' character with no concerted effort by any one individual or institution to follow up initial investigations. This lack of well-planned series of experiments involving a range of factors associated with a particular problem is still to a large extent typical of much present day research into teaching strategies and tactics and must therefore be expected to produce disjointed and unrelated findings.

The most notable development in experimental design during this period was the ready adoption of the rotation technique, in one form or another, whereby the different experimental groups are exposed in turn to the two, or three, teaching tactics being investigated. This first appeared in the earlier study of Kiebler and Woody (1923) and, although they do not acknowledge any influences, it is conceivable they adopted it from McCall (1923) who seems to have been the first to devise this technique. In this second phase it must be regarded as the standard technique, being employed no less than seven times in the better designed studies, while the rather more 'agricultural/botanical' technique of control and experimental group was used only twice.

Another important feature of design refinement to emerge was the use of a standard test, then rapidly becoming available, to pre-test pupils and students and to use these data for matching groups. Often this matching was very general with groups being checked for broadly similar average scores before any experimental treatment was carried out, but some workers, for example De Jarnett (1929) and Payne (1932), rearranged their groups to produce matching pairs – a much more sophisticated use of the data. Many workers were content to apply one standard I.Q. test, but others saw the need to produce rather more extensive profiles upon which to compare groups, and also used tests of reading, science aptitude, previous science performance, as well as I.Q. scores. It is interesting to note that one I.Q. test, the Terman Group Intelligence Test (TGIT), was used seven times although Horton (1928), working either at the same time as or before the others, had noted that it was possibly not a useful measure of potential scientific aptitude. Therefore, despite the fact that his own work involved chemistry topics, he employed Regent's scores in biology as a means of determining pre-treatment data. This he found had a higher correlation with chemistry scores than did the TGIT. Other workers of course may not have been aware of this finding; nevertheless they continued to use it uncritically together with other standard I.Q. tests.

During this second phase there was a marked improvement in the use of statistics. Although many workers still considered a simple comparison of means to be sufficient, at least thirteen of those for whom the data are available used further statistical manipulation. The first worker in this area to introduce a sound statistical technique would seem to be Carpinter (1926). In his own words: 'A very interesting statistical device was used to determine whether differences found in the different methods were significant differences or differences that might be expected due to chance. This device is called the critical ratio' (Carpinter 1926 p.798). Despite the use of the critical ratio some workers still did not seem to understand, or at least quote, the concept of statistical significance that this technique makes possible – for example Payne (1932). Those who did state whether their results were statistically significant or not still did not indicate the levels of confidence they were employing. Even such a comparatively careful worker as De Jarnett (1929) merely reported that his results were 'rather' significant.

Other forms of statistical treatment were also employed from time to time by various workers but their use was not as consistently popular as was the critical ratio. Kelley's sigma scores (Kelley 1923) were used by Knox (1927), who, incidentally, used the median as the central measure for his calculations.* McCall's influence (McCall 1923) was not confined to his contributions to experimental design: Wilkinson (1928) used his statistical technique, the 'experimental coefficient'. Pearson's Product Moment was used by Erikson (1929) to compare rankings and possibly by De Jarnett. What is of greater importance, however, is the large number of workers who either did not know of the existence of the appropriate statistical tools that were available, or did not appreciate their usefulness, or who chose to ignore them. Even as late as 1929 Shore and possibly Dykes were still employing a simple comparison of means only. Others obviously had a clear idea of what they wished to investigate, but presumably had an incomplete knowledge of statistics. Nash and Phillips (1927) calculated Standard Deviations to compare the spread of results found between their two experimental groups, but did not use them in any formal way. They also tried to compare rankings but again, with seemingly no knowledge of the appropriate statistical technique that might be applied to test the significance of the changes in rankings that they discovered. Erikson (1929) on the other hand, incomprehensibly, employed a sophisticated technique for the calculation of the Rank Coefficient but failed to use the, by then, very well known Critical Ratio concept and relied on a simple comparison of means for his main data.

---

* After its first definition by Pearson as the square root of the mean squared deviations about *the arithmetical mean* (Pearson 1894 pp.75-80) educationalists had confused the issue using modes and medians also as sources of the Standard Deviation. The situation had become so confused that Eells (1926) felt obliged to call for a generally agreed definition.

Many of the later studies of the period have proved unobtainable, but reports which are available indicate that adequate statistical methods were used. The final study of the period, that of White (1943), saw the introduction of yet another technique, namely the Chi Squared test.

The assessment tools used showed a marked improvement during the period, with much more care being taken with their construction. Objective tests became the norm, indicating a recognition of this type of test as a powerful and efficient means of measuring knowledge and factual recall. However, their use, if coupled with other types of tests, which would also indicate that the shortcomings of such implements as true/false, completion and multiple-choice tests was also recognised. Increasingly the need to pre-test items was acknowledged and the concepts of test validity and reliability were developed. Horton (1928) seems to have been the first to attempt to measure these attributes, although previously Nash and Phillips' (1927) report indicated some piloting of test items had been carried out. Hix (1933) also attempted some measurement of reliability although the fact that he reports the same reliabilities for all the tests does cast some suspicion on his efforts.

In general a steady improvement in test construction took place throughout this phase with Duel (1928) actually using a 'split-half' technique. Van Horne (1929) used tests that had already been developed for a previous study (viz. Carpinter 1926). While there was an element of pretesting in this it would have been a more efficient move had the tests been subjected to analysis for reliability and validity and such multiple use of instruments would have been even more advantageous had there been a concentrated effort by a group of investigators, as already discussed. The learning outcomes which the testing instruments were devised to measure were almost exclusively related to the recall of knowledge. However, in fairness it must be recorded that the need to measure other learning outcomes was quite clearly recognised. At the very beginning of the period under consideration Carpinter (1926) concluded that other abilities may well be improved by the individual or small group tactics of teaching but that the tests of his (Carpinter's) investigation did not measure them and, as he points out, no tests had been devised to assess such skills: 'We have as yet no adequate test for scientific attitude, appreciation, manipulative skill in handling apparatus, or scientific method of procedure' (p.802). Although such tests are now available we have yet to employ them in this particular field of enquiry.

Nevertheless, attempts were made by several workers during this period to develop such tools. Carpinter himself tried to produce a test of 'thinking' as did Van Horne (1929). One redeeming feature of an otherwise very poor study by Walter (1930) was his effort to test the ability to think, observe and remember, although no details are available as to how he did this. In fact the absence of examples from the tests devised was a consistent fault of most of the reports.

Very few studies were concerned with examining the higher cognitive skills. Perrussel (1930) apparently tried to test pupils' abilities to apply knowledge to new situations and Hix (1933) produced a test designed to measure a pupil's ability to distinguish fact from fiction. Duel attempted to measure transference of learning from one situation to another while Goldstein (1937) tried to investigate laboratory resourcefulness.

Dyer's study (1927) is particularly notable in that it is an early attempt to investigate the effects of the two teaching tactics on: 'building up certain outcomes in the minds of pupils and with reference to permancy of realizations once established' (p.66); 'realizations . . . are defined . . . by their feeling of familiarity; the method of establishing them calls for immediate personal experiences, or assembled personal experiences; selective realizations; and an avoidance of distracting realizations' (p.17). It would seem that he was trying to investigate the effects of the two teaching tactics in what we would now perhaps term the affective domain within the Bloomian area of 'receiving'. To provide a set of criteria against which to construct his tests, he analysed 35 teaching journals published between 1884 and 1922 and obtained a list of 49 objectives for the teaching of science from which seven basic outcomes were distilled. Although such work was not repeated again and his overall design was too weak – particularly in relation to the short time span based on only three lessons – for any real significance to be placed upon his findings, Dyer's was a notable pioneering investigation.

Horton (1928) was the first to look at the psycho-motor domain with tests of manipulative skills and was later followed by Hix (1933), Duel (1937) and White (1943). The interest here is not in the paucity of such studies but rather in the favourable comparison with later studies, a point that will be discussed when we consider the next phases of work.

While application of most of the criteria under consideration seems to suggest a general improvement it is interesting to note that this trend is marred by the appearance of a differentiation in teaching tactics. Duel (1937) commented on this when discussing earlier investigators: 'The instructor, as he performed the experiment, used the same language given in the laboratory instructions. He avoided any instruction by means of direct exposition . . . As far as can be ascertained from the reports of their studies, some of the later investigators, namely Walter, Knox, Johnson and Dyer, seem to have corrected *this faulty technique* and to have accompanied their lecture-demonstrations with explanations and discussions' (our italics, p.789). This would therefore seem to be a retrograde step in that it places demonstrations outside the exploratory strategy and makes the studies investigations of teaching strategies rather than tactics.

Many workers simply did not report this aspect of their investigations adequately enough for any judgements to be made, presumably thereby indicating the perceived lack of importance they gave to it. Only Horton (1928) can, once again, be cited as having taken particular care to maintain pure strategy and to investigate the effects of the two tactics only.

While we have argued that for a genuine comparison of the two teaching tactics of small group work (laboratory) and demonstration to be made, all conditions, other than the size of the groups carrying out the work, should be kept as constant or similar as possible, it is an inherent need of the demonstration that all pupils be working at the same pace all the time. It was Duel (1928) who noted that all the investigations relating to a comparison of demonstration and small group work had employed the 'even-front' system where all students worked at the same experiment at the same time. He rightly pointed out that this did not take into account an important potential of the small group tactic, that of allowing pupils to work at their own pace. He therefore compared the even-front system with 'rotation' or what we might now term a 'circus' system of teaching. A soundly constructed investigation led to the conclusion that the rotation system yielded better results than the even-front, at least in imparting essential knowledge.

This factor of speed of carrying out an experiment was investigated by other workers who found considerable 'savings' in time. For example, Van Horne (1929) noted a 20% saving in time while Walter (1930) found that work could be carried out 50% more quickly with demonstrations. Other investigators do not report data relating to this aspect and Wilkinson (1928) definitely found no such significant saving. It might well be argued that the speed and efficiency with which a demonstration can be carried out by a teacher is not necessarily an advantage and that pupils are deprived of the time necessary for them to absorb the information being given to them.

Most of the studies for which information is at hand were similar in that they investigated immediate recall of knowledge. The only exception to this was Goldstein (1937) who apparently tried to study laboratory resourcefulness only. With no details of his investigation being available (other than that reported by White (1943)) it is impossible to comment upon Goldstein's findings other than to say it is hardly surprising that he found laboratory work to be superior.

From Table 4 it can be seen that of the 20 studies investigating immediate recall, 8 found demonstration to be superior although one found it to be (questionably) statistically significant (De Jarnett 1929). Only four studies indicated that small group work might be superior for immediate recall, but none of these produced significant results. Finally eight workers could detect no real differences between the tactics and two studies indicated no statistical differences between them.

Table 4 Summary of the main findings of the Phase II studies

Results / Learning Outcome	Demonstration superior		Small group work superior		No differences favoured	
	Statistically significant	Not significant	Statistically significant	Not significant	No statistics employed	No Statistical difference
Immediate recall	1(?)	7	0	4	6	2
Delayed recall	1	4	0	1	2	2

Only eleven studies continued to investigate the effects of the teaching on delayed retention and again a predominance of non-significant findings favoured demonstration although one was significantly favourable. This last study was that of Brasure (1929) and is of interest in that it was also one of the minority investigations favouring small group work for immediate recall.

A comparison between Table 2 and Table 4 would seem to indicate that the apparent superiority of demonstration over small group work for immediate recall and that of small group work for delayed recall is less clearly indicated in the second phase than in the first. A similar trend is displayed but the results would appear to be less clear cut and, particularly when statistical techniques are employed, much more cautious interpretations are put on findings.

Attempts were made by some workers to explore the relationship between other factors and the two teaching tactics. No individual study specifically set out to investigate the possible different reactions of various age groups towards the different teaching. However, an inspection of Tables 3 and 4 shows that, of the researches for which data are available, fourteen involved pupils (i.e. up to and including high school level), while seven studies were carried out with students or subjects beyond the level of high school. An analysis of the findings reveals no particular pattern that might suggest the two tactics operate differently for the different age groups.

The influence of sex and 'intelligence' was also studied by some workers with the former factor showing no differences (Shore 1929 and De Jarnett 1929). Five investigations attempted to look at the intelligence factor. Knox (1927) in all his tests for immediate and delayed recall and application found that demonstration work was favoured by 'bright' pupils while laboratory tactics produced better results for 'dull' pupils. Shore (1929) on the other hand only reported intelligence differences in his delayed recall tests when he found high and low ability pupils performed better on the demonstration regime. Van Horne (1929) again found demonstration to be superior with both high and low intelligence pupils, but not significantly so. De Jarnett (1929) found only a 'rather' significant favouring of demonstration by the lower ability bands, and finally Payne (1932) also found that demonstration was favoured by students of lesser ability although his study was not a total comparison of the two tactics since demonstration was used merely as an introductory device before using normal small group actions.

Only one study of the period (Nash and Phillips 1927) attempted to look at individual differences and the effects of the two tactics. The attempt itself is probably more important than their tentative conclusions in that it is of interest to note that the researchers found some evidence to suggest that demonstration tactics maintained good correlations with I.Q. scores while small group work did not, thus possibly suggesting that the small group tactic allows individual differences to manifest themselves more readily (cf. Pruitt 1925). Bearing in mind the often small starting samples and other drawbacks of the studies, already noted, it is probably true to say that those findings no more than illustrate the continuing trend to make more sophisticated use of the data.

Only three other investigations are worthy of comment. Dykes' work (1932), reported very poorly by Fountain (1934), attempted to investigate the effects of altering the introduction of laboratory work into a normal diet of demonstration and a similar study by Hurd (1929), while not investigating the effects of demonstration against practical work, tried to explore the effects of different sized groups and the length of time devoted to laboratory work. Each produced no significant results. Gerberich and Roberds (1934) are notable for their pioneering introduction of the case study as a means of investigation. Unfortunately the data this produced were put to rather unsophisticated, and consequently relatively poor, use.

This second phase is characterised by a steady improvement of design, testing and the association of statistical techniques, together with a decline in the purity of teaching tactics and a seemingly continued build up of evidence favouring demonstration work, at least as far as short term retention is concerned. However it is important to note that where the analysis of data is statistically sound, only rarely are any real differences detected and it is probably fair to suggest that if all the data had been treated in a similar manner this conclusion would have been found to hold true for most, if not all, investigations. Cunningham (1946), reviewing a similar period, suggests that demonstration work could be used where learning is complicated, where apparatus is complicated and expensive and where students can make mistakes in interpretations. The individual or small group tactic, he maintains, should be used only where experiments are short and easy and where the teacher is striving for maximum individual differences, the development of laboratory skills, problem solving skills and resourcefulness. The present authors would wish to be much more cautious than this and suggest that perhaps some of these tentative ideas might form the basis of further researches to be conducted under much more rigorous conditions.

A further trend to be emphasised is that of the extension of the interests of the researchers and their attempts to investigate aspects of student behaviour and educational outcomes other than the recall of information. This however must have caused frustration as it was realised by the workers that adequate tools needed to be developed before higher cognitive, affective and psychomotor skills could be adequately investigated. Such excursions into the finer details of the problem were not altogether fruitless however and the idea grew, albeit subconsciously, that true differences between teaching tactics might only be found when the effects on smaller pupil groups or individuals were properly investigated, e.g. Nash and Phillips (1927) and Johnson (1928), or that the effects of mixing and timing particular teaching tactics needed to be fully studied, e.g. Payne (1932) and Fountain (1934). Perhaps there was already a realisation that teaching tactics have more effect in the micro situation, since they are more specific and localised in their influences and that global designs are only effective in detecting the rather coarse influences of different strategies operating at the macro level. This is summed up admirably by Noll (1930b): 'The most striking implication of these studies would seem to be that our methods of instruction in college chemistry can undergo considerable change and manipulation without our being able to detect any great effect on the results, at least in the present state of educational measurement' (p.303).

While Noll was referring to chemistry teaching and in the context of an investigation into effectiveness and individual laboratory work only, it would seem that these comments can be applied to all areas of science teaching and it is striking that as adequate statistics come to be applied to the data, evidence favouring one teaching tactic over another diminishes dramatically. This is a trend that will be seen to continue up to the present day investigations, at least where gross, overall changes in student skills are being studied.

C. PHASE III 1946-1960

Not surprisingly after the second World War, studies picked up slowly. The main features of these investigations are summarised in Table 5. Again all the studies are from the USA and with the exception of the first study (Mallinson (1947)), all are concerned with physics students.

The work of this phase is marked by a sophistication and maturity that would seem to indicate that a new generation of investigators was being trained. Experimental procedures show very marked improvement with all five workers employing random block designs. Null hypotheses are stated, and data is analysed using analysis of variance and covariance.

Table 5. Summary of the Phase III studies, 1946-1960

AUTHOR COUNTRY & SUBJECT	SAMPLE AND AGE GROUP	DESIGN OF INVESTIGATION	STATISTICS	INSTRUMENTS	PURITY OF STRATEGY	RESULTS	COMMENTS
Mallinson (1947) USA Physics							No other details
Kruglak and Carlson (1953) USA Physics	Students	2x2 random block; null hypothesis stated; learning outcomes to be investigated stated. Experimental group all demonstration. Control worked in pairs. 'Zero' control no laboratory work	ANOVA & COVAR	Standard pre and post tests. Relatively crude	–	No sig. diffs. between tactics w.r.t. immediate recall or knowledge	Acted as pilot study for subsequent investigation
Kruglak (1952a) USA Physics	108 students 4 instructors	2x4 random block with equal sub-classes. 3 null hypotheses set up (see text) 4 experimental & 4 control groups. Care taken to keep all factors equal	ANOVA & COVAR	Mechanics theory, Laboratory and two practical, tests. All pre-tested in pilot study above	Poor	No sig. diffs. between tactics w.r.t. immediate reacll	Previous study was pilot investigation
Kruglak (1952b) USA Physics	38 students 2 instructors	2x2 random block; each instructor taught a control and experimental groups. All factors equal	ANOVA & COVAR	Carefull construct. Validity & reliability good	Poor	No. sig. diffs. between tactics w.r.t. immediate recall. Lab. superior (1% level) w.r.t. short & long term lab performance	Between instructor no interaction effects. Very well reported
Balkziak (1953) USA Physics	144 students 1 teacher	2x3 random block = 70: 30 Men/Women	ANOVA & COVAR	Careful construct. Reliability & validity good	–	No sig. diffs. between tactics w.r.t. immediate recall, lab. performance, science attitude	Demonstration, small group and pupils working in pairs were compared
Ward (1956) USA Physical Science	Students all women	Null hypotheses stated. 2x2 random block	ANOVA & COVAR	Careful construct. Reliability & validity good	Poor	No sig. diffs. between tactics w.r.t. recall, recognition & understanding	Very well reported

The work of Kruglak is particularly worthy of detailed consideration. After an elaborate pilot study (Kruglak and Carlson 1953) he modified his design by including four instructors in a 2 x 4 randomised block. Tests were refined as a result of the pilot study and an analysis of variance and covariance was used to test three null hypotheses viz: i) that there is no significant difference in the learning outcomes of students who perform laboratory experiments in elementary college physics by the conventional method (small group work) and students for whom the same experiments are demonstrated. ii) that no differences are traceable to differences in instructors, iii) that no differences are assignable to the interaction between instructors and methods (tactics as defined in this paper). Four outcomes were measured by means of a mechanics theory test, a laboratory written test and two laboratory practical tests. No statistically significant results were obtained except in the case of the ability to manipulate simple apparatus, where the conventional group was found to be superior to the demonstration group. No other evidence was obtained that in any way indicated rejection of the null hypotheses.

An additional analysis, using data obtained from the no-laboratory 'zero control' (Kruglak 1953), indicated that pupils who received laboratory instruction by either small group or demonstration tactics were, not surprisingly, superior to those who received no laboratory instruction, as far as the three tests designed to measure laboratory achievement were concerned. However, no significant differences were found between any of the groups on the theory tests. The work of Balcziak (1953) was similarly well designed, employing sound analysis techniques and using carefully constructed and pretested measures. Again no significant differences were found between any of the groups and on any of the tests for scientific information, science attitudes or laboratory performance.

In these well reported investigations, care was taken to keep the teaching strategies pure, with the exception of Ward's (1956) inquiry. He placed a different emphasis on teacher involvement thus introducing a further tactical variable into the study.

The amount of teacher framing (see p. 111) was very strong in the demonstration group but deliberately pupil orientated in the small pupil group, to the extent that course objectives were determined by the group as were the individual pupil assessments. So although the subject matter was teacher controlled in both groups, the relative strengths of pupil/teacher framing were closely reflective of the differences between teaching strategies.

Analysis indicated no overall superiority of one teaching tactic over the other, but significant differences were detected at what may be called the micro levels of the investigation. These are summed up by Ward thus:

a. the group method resulted in longer retained more-understanding type of learning and also in greater individual differences in such learning with more able students;
b. the lecture demonstration resulted in greater expression of individual

differences and in longer retained more-understanding learning in less able pupils; and

c. the lecture demonstration resulted in greater expression of individual differences in longer retained recall-recognition type learning in lesser able three-quarters of the students.

This result is interesting when compared with the rather different views of Nash and Phillips (1927).

Bearing in mind that the tactics were quite markedly different as to the degree of student/teacher framing, it might be suspected that some detailed differences would be detected. In addition it is important to note the emphasis on the individual differences. With this small but highly reliable set of investigations, it is noticeable that no overall significant differences between the two teaching tactics of demonstration and small group work were detected. Indeed only when smaller, individual differences and relationships were investigated were there any noticeable differences in the effects of the tactics. Indeed Kruglak and Wall (1959) were prompted to comment 'It is most unlikely that future investigations will show any significant differences between conventional laboratory and demonstration groups if the criterion measures are the stereotyped, paper-and-pencil tests of facts, principles and applications' (p.154).

D. PHASE IV 1960-1980

This 'post-sputnik' period has seen a major shift in the emphasis of educational research towards problems associated with curriculum development. In the USA studies of the experimental type would seem to have decreased somewhat, whilst, for the first time, workers in Great Britain have attempted to investigate the problem under review in this paper. However the number of studies is so small that no table of findings has been produced.

The work of Heaney (1969 and 1971) was the first to come from the UK. Unfortunately the investigation was not strictly a comparison of small group and demonstration teaching as each of the three tactics she examined, viz, 'heuristic-guided discovery', 'cook-book' and 'didactic-with-demonstrations' employed quite distinctive strategies. Therefore, despite a carefully designed investigation coupled with sound statistical techniques and well produced tests, the results must be regarded as relating to a comparison of strategies.

The data were subjected to statistical analysis and degrees of significance were attached to some of the findings, although the rather high 5%, and even 7% levels were accepted by Heaney. Furthermore, she often presented no more than simple graphical displays which were taken as demonstrating significant results without calculations of the degrees of significance being included. It is possible that a more rigorous treatment of the data might have yielded more conservative conclusions. However, her work does seem to indicate that the heuristic strategy was more successful than the other two in the three outcomes she investigated, viz. learning, improvement and attainment. In particular it was found to be superior as a means of improving problem solving skills. Only in the one aspect of high order cognitive skills when being taught and tested concurrently with learning did the evidence favour the 'didactic-with-demonstration' strategy.

Despite slight evidence, Heaney makes one very strong and disturbing comment: 'The "didactic-with-demonstration" approach is harmful to the development of problem-solving and practical skills; and the harm is greatest for pupils of high mental age' (1971 p.226). This is not in agreement with other work in the field.

The present authors (Garrett 1978 and Garrett & Roberts 1980) worked with nine teachers in six schools and a total of 305 11-12 year old pupils. By means of a rotation technique all pupils were exposed to both tactics of small group work and demonstration teaching and every teacher taught both curriculum units by both tactics. In this way no control group was required. Although pupils were not assigned to groups in a random manner, pretests indicated that the various groups were comparable.

Analysis of the data was carried out using a comparison of t-tests and analysis of variance. Extreme care was taken to ensure that both teaching tactics were as pure as possible and were taught within the same 'Guided Discovery' exploratory strategy. All assessment tools were pretested and found to be reliable and were designed to assess simple knowledge and understanding only of facts, observations and experimental techniques.

In general no overall significant differences were found between the two tactics even when the scores of boys and of girls were isolated and analysed separately. It was only when small, micro groups and factors were considered that any significant results were noted at all. For example, on one set of the teaching materials only, the ethnic minority* performed significantly better at the 1% level when taught by demonstration. Even when considering average/superior and inferior pupils there was no favouring of either tactic by any group. In fact the most consistent indications were that teachers and the materials were more important factors in causing any differences than were the teaching tactics.

A further experiment was carried out by Garrett (1978) using a rating scale devised to allow all the test items to be rated as either dependent, independent or neutral with respect to the need for laboratory practical work. Pupil scores from each of these categories of items were isolated and the attainment of the demonstration and small group pupils were compared. Again no significant differences were detected, perhaps indicating that the type of question – or the raters' opinions-of the types of questions – were independent of the teaching tactic used. However, such a conclusion must be treated cautiously as the items were only within the range of simple knowledge and understanding; items of higher cognitive types might produce different results.

---

* The ethnic minority was composed entirely of pupils with a parental background outside Europe – mainly Asian and Caribbean.

Other current work is that by Atkinson (personal communication) which is being carried out in Australia. In an attempt to obtain information about the characteristic of instructional procedures that may be retained in a student's memory, four classes at level 10 in a metropolitan, non-streamed High School were employed with the two class teachers taking their usual lessons. Classes were randomly allocated to either demonstration or small group practical and studied a linear programme developing a series of intellectual skills and verbal knowledge associated with the General Gas Equation. Two practical sessions, one on Boyle's Law and the other on Charles' Law, were carried out at appropriate points in the programme.

Retention and transfer of propositions and intellectual skills were assessed using an 18 question Retention Test given individually in an interview situation 2 days and 6 weeks following completion of instruction. After a written answer was given to each question, each student was asked 'what thoughts and/or pictures flashed through your mind while you were deciding how to answer the question?' Their oral responses were tape recorded. Following the Retention Test the students were shown two photographs of the apparatus used in the science experiments and asked 'Can you tell me if you can remember this experiment and, if so, what you can remember about it? Oral responses were tape recorded. Oral responses following cueing with photographs revealed that 6 weeks after instruction, an episode relating to a science experiment was recalled by almost all students in the case of the Boyle's Law experiment and, with Charles' Law, by all students in the small group treatment but only three quarters of the students in the teacher demonstration treatment. However when answering the questions in the Retention Test, in only one question did many students report linking to the science experiments.

It appears that a variable or variables, other than the treatment, resulted in students better retaining intellectual skills but not better retaining verbal knowledge or transfer of intellectual skills when these were learned in association with science practical experiments carried out in small groups rather than viewing experiments demonstrated by the class teacher.

With the rapid development of technology for use within schools, the production of films has become important and considerable film material is now available. The demonstration film is almost equivalent to teacher demonstration with the important difference that no direct pupil response is possible. Therefore work on the effectiveness of filmed materials must be of direct relevance to this review.

Palmer (1971) and Kempa and Palmer (1974), looking at the effectiveness of video-taped demonstrations in the learning of manipulative skills in practical chemistry in university undergraduate courses, have shown that whilst there was little difference between student performance in relation to the cognitive aspects of the skills being taught, there were marked differences in manipulation skill performance, a not altogether unexpected result. However, they also showed that those receiving the video film were more competent in completing the manipulative skills than were those who had merely been given written instructions.

Working with 10th grade Israeli High School pupils, Ben-Zvi *et al.* (1976) studied the effectiveness of filmed demonstrations in the teaching of chemistry and found that, with the exception of the manipulative skills area, filmed demonstrations were an effective substitute for individual laboratory work and also that pupils were not affected adversely in the problem solving situation.

There would seem to be no other empirical contributions from Europe other than that of Heyer & Rannow (1969) but since this research only compares percentages it is of little consequence as a source of reliable modern data. All other work from the European continent that has been traced seems to be of a non-empirical nature, e.g. Rossa (1963).

There are two features of the last two phases to be considered further. First, we must note the sophistication of the experimental designs and the statistical analysis. Although this is accompanied by a decline in the purity of the teaching tactics, which deteriorates to be almost a comparison of strategies (e.g. Ward 1956 and Heaney 1969), there is a marked widening of the scope of the studies with many more pupil factors and educational outcomes being investigated. Consequently much contradictory evidence emerges with neither tactic being clearly favoured. A similar situation was found in the case of investigations of related tactics, such as those of Novak (1958), Rainey (1965) and Ruja (1954).

Second, these last phases are marked by a distinct drop in the number of studies that have been carried out. Could it be that there has been a less open-minded attitude by teachers and science educators, or have their efforts been directed towards other tasks, in particular the development of a large number of curriculum projects? It may however be, as Nisbet (1974) has noted, that empirical research of the type considered here is rather naive and can resolve only relatively minor issues. It is also possible that the reduction in the number of relevant studies is a reflection of the extent to which researchers have widened their activities beyond a concern with a comparison of small group work and demonstration. When reviewing the 1960's Ramsey and Howe (1969 a & b) found a considerable number of empirical studies had been carried out, but the rather more diverse strategies and tactics being employed in schools were reflected in their researches. Thus, they found 11 reports on team teaching, 16 dealing with aspect of programmed learning, 17 comparing audio-visual tactics, 8 investigated field trips, 6 classroom interaction studies, 5 concerned with content integration and only 11 studies concerned with aspects of laboratory instruction of one sort or another. It might therefore be expected that, with these other classroom activities to be examined, the number of studies of laboratory and demonstration tactics might well be reduced to reflect their new position among other tactics now available. Thus there are several related studies in this area although not focussed directly on the specific problem of this paper, e.g. Coulter (1966) who investigated the effects of the two strategies of inductive and deductive laboratory only using inductive demonstration as a touchstone. Similar examples of related studies are to be found in Oliver (1965) and Newman (1967).

The studies analysed can be assessed and criticised on two levels. So far we have been concerned with a detailed consideration of the strengths, weakness and specific value of each individual study as measured against the criteria already defined, with a view to exposing any general trends that might be discernible. This would seem to have produced no clear cut indication of the superiority of one tactic over the other and the overall evidence would seem to suggest that there was no difference between them at least in any generalisable way. This in itself prompts us to suggest that as long as researchers look for gross overall changes, or differences, in pupil outcomes, then simple changes in teaching tactics will not produce overall measurable results. As groups of several tactics are employed within any strategy the effects of any one tactic must be relatively weak, diluted as it is within the strategic pool. It might therefore be argued that investigations of the type reviewed in this paper are of little use as they cannot, by their nature, yield clear cut results.

This view leads us to consider the second, much wider, level at which these investigations can be criticised; a questioning of the whole approach to educational research. It is suggested that the research reviewed, irrespective of the experimental design and techniques employed, can at best only provide good answers to poor questions because it does not always ask the right questions. The basic design employed, with varying degrees of skill, in all these investigations is the classical method. The use of this 'agricultural-botany' approach in educational studies has been roundly criticised and judged as wanting by several workers and in particular Parlett and Hamilton (1972). They see five main shortcomings. These can be briefly summarised as follows.

i. Researchers tend to think in terms of 'parameters' and 'factors' rather than 'individuals' and 'institutions'.
ii. Before-and-after research designs assume that little change takes place during the period of study.
iii. The pre-occupation with 'objectivity' and quantitative data causes much potentially important data to be disregarded as 'subjective', 'anecdotal' or 'impressionistic'.
iv. Statistical generalisations tend to be insensitive to localised and unusual effects.
v. Such studies rarely satisfy potential users of the findings in that they do not provide them with worthwhile answers to their questions.

While Parlett and Hamilton are mainly concerned with evaluation studies their basic criticisms can also be levelled at the type of research described in this paper. We would accept that the traditional approach to educational research does not provide complete answers, but the alternatives, while recognising the important fact that the teaching/learning situation is highly complex, do not necessarily provide a complete or exclusive route to its investigation. Both approaches have their value and must take their place in the range of research techniques available to the investigator. Far from advocating the rejection of the more traditional ways of research we would suggest that they should be used in a rather less restricted way to explore many areas that have been largely ignored. As Shulman (1970) says 'neither an acceptance of the current practices nor a monolithic rejection of them is likely to solve the problems of educational research' (p.371).

Acknowledging that the type of investigation described in this paper might well have been asking poor questions, in what ways might questions be improved? It is possible, for example, that some questions have been too limited. Thus, previous investigations have concentrated almost exclusively upon paper-and-pencil tests of knowledge with the higher levels of the cognitive domain and the affective and psychomotor domains almost totally ignored.

One of the most extensive works relating to the coverage of educational outcomes is that of Yager, Englen & Snider (1969); this represents an example of the way in which classical research into educational practice can usefully be expanded. Yager *et al.* imply in their conclusions that an investigation of the existence of some possible aptitude-treatment interaction could well be fruitful. This was also hinted at by Garrett (1978), but he suggested that this dimension should be extended to incorporate teacher and material compatability, including in the latter both teaching and testing materials. The success of a particular tactic with a particular student might also be affected by the suitability of the material relative to that tactic, the type of tests devised and the attitude of the teacher towards the material.

The timing of the introduction of a tactic may also be a crucial factor and one worthy of further investigation. As Cronbach (1966) has pointed out 'A particular educational tactic is part of an instrumental system; a proper educational design calls upon that tactic at a certain point in the sequence, for a certain period of time, following and preceding certain other tactics. No conclusion can be drawn about the tactic considered by itself . . .' (p.77). This has also been suggested by Yager *et al.* (1969) and again by Garrett (1978) who suggested that a 'tactic mix' may well be a critical factor.

When discussing the paper by Yager *et al.* (1969), Shulman & Tamir (1973) make the following observations: 'Have we succeeded in measuring all possible outcomes? Have we not fallen into the trap of using available standardized instruments which have not been designed specifically to test the outcomes of laboratory work and therefore have failed to discriminate and to indicate existing although hitherto unnoticeable differences?' (p.1121). Such a view is also supported by Dubin and Taveggia (1968) who suggested that by concentrating upon content objectives rather than process objectives, research workers have missed the point and, as Rowntree (1974) sums it up, 'very real differences between the outcomes of strategies (tactics) may have been not so much "not measurable" as merely "not measured"' (p.102).

The future use of the traditional methods of research in this context, while requiring considerable rethinking, is certainly important and must be directed to exploration of a wide range of problems.

Perhaps this points the way for the next stage of investigations. It has already been noted that Kruglak and Wall (1953) considered it unlikely that significant differences between what has been defined here as tactics, would be detected by tests of facts, principles and applications; subsequent work would seem to bear out that comment. Indeed, while it is impossible to sum up the findings and produce any overall conclusions as to the effectiveness or otherwise of the two tactics, it is possible to formalise the surmise of Kruglak and Wall into a hypothesis for testing. All the foregoing studies would seem to indicate that while teaching *tactics* are being compared no overall significant differences will be detected between the performances of any homogeneous groups of students. Indeed, only when differing teaching *strategies* are being investigated will any such blanket effects be detectable. This is illustrated well by Heaney's (1969) study. Her 'heuristic' approach clearly employs a different *strategy* from the 'didactic-with-demonstration' and 'cook-book'; hence a clear difference in effectiveness between it and the other two was noted. However, the 'didactic' and 'cook-book' are, in her experiment, both firmly placed in the *expository strategy* and are merely different *tactics* within it; consequently no clear distinctions emerge between them.

This may be summarised thus: *strategies* functioning at the macro levels may cause major (macro) effects to be detected whilst any differences in the effectiveness of *tactics* will only be detectable at the micro levels within the classroom. No one tactic is better than another *per se*. All tactics have their uses and the implication is that, for meaningful and useful research to be carried out, workers should attempt to identify the most effective blend of teaching tactics to employ in any given situation.

We could therefore suggest that the way forward might fruitfully involve a re-examination of the function of the school laboratory in science teaching with a view to developing suitable instruments for measuring the outcomes which it is assumed are produced in the practical situation. Any investigation of the suitability or effectiveness of teaching tactics should be rather more extensive that the hitherto 'clinical' experimental situation and should include the study of a wide range of learning and attitudinal outcomes in a multivariate situation. Additionally, observation of the possible effects of changes in tactics should extend beyond the mere recording of data from a battery of tests, to take into account the whole environment in which the results were obtained, in particular the role of the teacher and his use of the teaching and testing materials.

REFERENCES

Note: The authors attempted to obtain copies of all items listed below; where this proved impossible the source of the reference has been quoted in brackets.

ATKINSON, P. A. 1980 *Instruction – Memory – Performance. The Influence of Practical Work in Science on Memory and Performance.* Unpub. Ph.D. thesis, Monash University.

ANIBEL, F. G. 1926 Comparative effectiveness of the lecture-demonstration and individual laboratory method. *J. Educ. Res.* **13** (5), 355-365.

BALCZIAK, L. W 1953 *The role of the laboratory and demonstration in college physical science in achieving the objectivity of general education.* Unpub. Ph.D. thesis, Univ. of Minnesota.

BEN-ZVI, R. HOFSTEIN, A., SAMUEL, D. & KEMPA, R. F. 1976 The educational effectiveness of filmed experiments in high school chemical education. *J. Chem. Educ.* **53**.

BERNARD, J. D. 1941 *The lecture demonstration v the problem solving method of teaching college science courses.* University of New York Dissertation (White 1943).

BERNSTEIN, B. 1971 On the classification and framing of educational knowledge. In Young M.F.D. (Ed) *Knowledge and Control.* Collier-Macmillan, London.

BOENIG, R. W. 1969 *Research in Science Education 1938 through 1947.* Teachers College Press, University of Columbia, New York.

BORETZ, N. 1930 *Individual experimental versus pupil demonstration methods in High School General Science.* Unpublished M.A. thesis, University of New York (Cunningham 1946).

BOWERS, W. G. 1924 The importance of laboratory work as compared with text-book work, etc. in the study of chemistry. *School Science & Maths,* **24**, 606-613.

BRASURE, R. E. 1929 *An experimental study of the teacher demonstration and the individual laboratory methods in the teaching of physics.* Unpublished M.Phil. thesis, University of Wisconsin.

CALDWELL, O. W. 1921 *Science Teaching.* The Gary Public School General Education Board. (Quoted in Carpinter 1926).

CARPINTER, W. W. 1926 A study of the comparison of different methods of laboratory practical on the basis of the results obtained on tests of certain classes in High School chemistry. *J. Chem. Educ.* 3(7), 789-805.

CONNELL, L. 1971 Demonstration and individual practical work in science teaching; a review of opinions. *The School Science Review,* **52**(180), 692-703.

COOPRIDER, J. L. 1922 Oral versus written instructions and demonstration versus individual work in high school science. *School Science & Maths.* **22**, 838-844.

COOPRIDER, J. L. 1923 Laboratory methods in High School science *School Science & Maths.* **23**, 526-530.

COULTER, J. C. 1966 The effectiveness of inductive laboratory, inductive demonstration and deductive laboratory in biology. *J. Res. in Sci. Teaching,* **4**, 185-186.

CRONBACH, L. J. 1966 The logic of experiments on discovery. In:Shulman, L. S. & Keislar, E. R. (Eds) *Learning by Discovery. a critical appraisal.* Rand McNally, Chicago.

CUNNINGHAM, H. A. 1920a *Under what conditions, in High School Science, is Individual Laboratory Work Preferable and when does the Lecture Demonstration Give Better Results?* Unpub. Masters thesis, Dept. of Education, University of Chicago.

CUNNINGHAM, H. A. 1920b Individual laboratory work versus lecture demonstration in high school science. *University of Illinois Bull.* **18**, 105-107.

CUNNINGHAM, H.A. 1924a Laboratory methods in natural science teaching. *Schools Science & Maths.* **24**, 709-715.

CUNNINGHAM, H. A. 1924b Laboratory methods in natural science teaching. *School Science & Maths.* **24**, 848-851.

CUNNINGHAM, H. A. 1946 Lecture demonstration versus individual laboratory method in science education – a summary. *Science Educ.* **30**, 70-82.

CURTIS, F. D. 1926 *A Digest of Investigations in the Teaching of Science in Elementary and*

Secondary Schools (1971 Reprint) Teachers College Press, Teachers College University of Columbia, New York.

CURTIS, F. D. 1931 *A Second Digest of Investigations in the Teaching of Science* (2nd Ed. 1971) Teachers College Press, Teachers College University of Columbia, New York.

CURTIS, F.D. 1936 *A Third Digest of Investigations in the Teaching of Science* (2nd, ed. 1971) Teachers College Press, Teachers College University of Columbia, New York.

DE JARNETT, W. W. 1929 *A study of the lecture demonstration and individual laboratory methods of teaching biology in a small high school* Unpublished M.A. thesis, University of Kansas.

DOWNING, E. R. 1925 A comparison of the lecture-demonstration and the laboratory methods of instructions in science. *School Review*, 33, 688-697.

DUBIN, R. & TAVEGGIA, T.C. 1968 *The teaching-learning paradox: a comparative analysis of college teaching methods.* Eugene: Centre for the Advanced Study of Educational Administration. University of Oregon.

DUEL, H. W. 1928 The even-front system versus the rotation system in laboratory physics. *School Review*, 36, 447-454.

DUEL, H. W. 1937 Measurable outcomes of laboratory work in science; a review of experimental investigations. *School Science & Maths.* 37, 795-810.

DYER, J. H. 1927 *An Analysis of Certain Outcomes on the Teaching of Physics in Public Schools with an Investigation of the Efficiency of a Laboratory Method in Establishing such Outcomes.* Westbrook Publishing Co., Philadelphia.

DYKES, C. (No title cited by Fountain 1934). Thesis for Master's Degree, George Peabody College for Teachers.

EELLS, W. C. 1926 A plea for a standard definition of the standard deviation. *J. Educ. Res.* 13(1), 45-52.

ELDER, A. L. 1939 The lecture-demonstration method versus individual laboratory work in chemistry. *Science Education*, 23, 209-215 (in Cunningham 1946).

ERIKSON, H. A. 1929 *Laboratory experiments versus demonstration: Experiments in high school chemistry.* Unpub. M.A. thesis, New York University (in Cunningham 1946).

EWING, E. 1926 *Individual laboratory versus Teacher Demonstration Method of Teaching High School Chemistry.* Unpub. Master's thesis, Temple University Philadelphia (Keiser 1933).

FOUNTAIN, C. R. 1934 Laboratory investigation versus laboratory verification. *The Physics Teacher (Am. J. Physics)*, 2, 177-178.

GAGE, N.L. 1978 *The Scientific Basis of the Art of Teaching.* Teachers College Press, Columbia University, N.Y.

GALPERIN, P. Ya. 1953 An experimental study in the formation of mental actions. In: Simon, B. (Ed) *Psychology in the Soviet Union*, Routledge & Keegan Paul, London.

GALTON, M. 1979 Strategies and tactics in Junior School Classrooms. *Brit. Educ. Res. J.* 5(2), 197-210.

GARRETT, R. M. 1978 *Pupil experimentation versus teacher demonstration in lower secondary science teaching: a comparative study of the development of simple cognitive skills.* Unpub. M.A. thesis, University of Keele.

GARRETT, R. M. & ROBERTS, I. F. 1979 Pupil experimentation. Has the pendulum swung too far? *Research in Assessment II.* Chemical Society Assessment Group Annual General Meeting, University of Warwick, 100-112.

GERBERICH, J. R. & ROBERDS, W. M. 1934 Individualized instruction for superior students in introductory college physics. *Science Education*, 18(1), 28-32.

GILBERT, J. P. 1910 An experiment on methods of teaching zoology. *J. of Educ. Psychol.* 1, 321-332.

GLASS, G. V. 1976 *Primary, secondary and meta-analysis of research.* In Shulman, L.S. (Ed) Review of research.

GOLDSTEIN, P. 1937 Student laboratory work versus teacher demonstration as a means of developing laboratory resourcefulness. *Science Education*, 21, 185-193 (Cunningham 1946).

GOOD, C. V. 1930 Research in secondary school methods. *J. Educ. Res.* 22(1), 9-30.

HARWELL, H. I. 1933 *Practical outcomes of the laboratory method and the lecture demonstration method in teaching high school chemistry by the use of concepts.* Unpub. M.A. thesis, University of Kansas (De Jarnett 1929).

HEAFFORD, P. E. 1965 *The Teaching of Science.* In: Peterson, A.D.C. (Ed) *Technology of Teaching Vol.2 Secondary Education* Pergamon Press, London, 81-105.

HEANEY, S. 1969 *The effects of three teaching methods and the ability of young pupils to solve problems in Biology: an experimental and quantitative investigation.* Unpub. M.A. thesis, University of Keele.

HEANEY, S. 1971 The effects of three teaching methods and the ability of young pupils to solve problems in biology: an experimental and quantitative investigation. *J. Biol. Educ.* 5, 219-228.

HEDGES, L. V. 1978 *A meta-analysis of studies of four teaching behaviour variables.* Stanford, California, School of Education.

HEYER, C. & RANNOW, W. 1969 Auswikungen quantitativer Schulerexperimente auf die politisch-moralische Bildung und Erziehung. *Chemie in der Schuler*, 16, 418-424.

HIX, E. L. 1933 *The value of laboratory work in High School Physics.* Unpub. M.A. (Education) thesis, State College of Washington.

HORTON, R. E. 1928 *Measurable Outcomes of Individual Laboratory Work in High School Chemistry.* Teacher's College, Contributions to Education 303, Columbia University.

HUNTER, G. W. 1922 An experiment in the use of three different methods of teaching in the classroom. *School Science & Maths.* 21, 875-890.

HUNTER, G. W. 1923 An experiment in the use of three different methods of teaching in the classroom. *School Science & Maths.* 22, 20-32.

HURD, A. W. 1928 Present inadequacies and suggested remedies in the teaching of High School Science. *School Science & Maths.* 28, 637-639.

JOHNSON, P. O. 1928 A comparison of the lecture-demonstration, group laboratory experimentation, and the individual laboratory experimentation methods of teaching high school biology. *J. Educ. Res.* 18(2) 103-111.

KAHN, P. A. 1942 *An experimental study to compare the laboratory method of instruction with individual demonstration in elementary college biology.* Unpub. Master's thesis, The College of the City of New York (Cunningham 1946).

KEISER, L. B. 1933 *The present status of the lecture-demonstration versus the individual laboratory method of teaching science in the high school.* Unpub. M.A. thesis, College of the City of New York.

KELLEY, T. L. 1923 *Statistical Method.* MacMillan Co. New York, 116.

KEMPA, R. F. & PALMER, C. R. 1974 The effectiveness of video-tape recorded demonstration in the learning of manipulative skills in practical chemistry. *J. Educ. Technology*, 5(1), 62-71.

KIEBLER, E. W. & WOODY, C. 1923 The individual laboratory method versus the demonstration method of teaching physics. *J. of Educ. Res.* 7(1), 50-58.

KNOX, W. W. 1927 The demonstration method versus the laboratory method of teaching High School chemistry. *School Review*, 25, 376-386.

KRUGLAK, H. 1952a A comparison of the conventional and demonstration methods in the elementary college physics laboratory *J. Exptl. Educ.* 20, 293-300.

KRUGLAK, H. 1952b Experimental outcomes of laboratory instruction in elementary college physics. *Am. J. of Physics*, 20, 136-141.

KRUGLAK, H. 1953 Achievement of Physics students with and without laboratory work. *Am. J. of Physics*, 21, 14-16.

KRUGLAK, H. & CARLSON, C. R. 1953 Performance tests in physics at the University of Minnesota. *Science Educ.* 37, 108-121.

KRUGLAK, H. & GOODWIN, R. A. 1953 Laboratory achievement in relation to the number of partners. *Am. J. of Physics*, 23, 257-264.

KRUGLAK, H. & WALL, C. N. 1959 *Laboratory Performance Tests for General Physics.* For the National Science Foundation; Western Michigan University, Kalamazoo, Michigan.

LAWLER, E. P. 1970 *Research in Science Education 1953 through 1957.* Teachers College Press, University of Columbia, New York.

MALLINSON, G. G. 1947 The individual laboratory method compared with the lecture-demonstration method in teaching general biology. *Science Education,* **31**, 175-79.

MAYMAN, J. E. 1912 *An experimental investigation of the book method, lecture method and experimental method of teaching science in the elementary schools.* Unpublished PhD thesis. New York City, Bureau of Educational Research.

McCALL, W. A. 1923 *How to Experiment in Education.* MacMillan Co., 187-207.

McKEACHIE, W. J. & KULIK, J. A. 1975 Effective College Teaching. In: Kerlinger, N. F. (Ed) *Review of research in education,* Vol.3, Itasca, Illinois. Peacock, F.E., 165-209.

MUKERJI, N. P. 1940 An investigation of ability in work in groups and in isolation. *Brit. J. Psychology,* **30**, 352-356.

NASH, H. B. & PHILLIPS, M. J. W. 1927 A study of the relative value of three methods of teaching high school chemistry. *J. Educ. Res.* **15**(5), 371-379.

NEWBURY, N. F. 1965 *The Teaching of Chemistry.* Heinemann, London (3rd Ed.).

NEWMAN, E. N. 1967 A comparison of the effectiveness of three teaching methods in high school biology. University microfilms, Ann Arbor, Michigan. (In Ramsey & Howe, 1969).

NISBET, J. 1974 Fifty years of research in science education. *Studies in Science Educ.* **1**, 103-112.

NOLL, V. H. 1930a *Laboratory instruction in the Field of Inorganic Chemistry.* Unpub. Doctor's Dissertation, University of Minnesota.

NOLL, V. H. 1930b Optimum laboratory emphasis in College Chemistry. *School and Society,* **32**, 300-303.

NOVAK, J. D. 1958 An experimental comparison of a conventional and project centred method of teaching a college general botany course. *J. Experimental Educ.* **26**, 217-230.

OLIVER, M. 1965 The efficiency of three methods of teaching high school biology. *J. Exptl. Educ.* **33**, 289-295. (In Ramsey & Howe 1969).

PALMER, C. R. 1971 *The Use of Recorded Demonstration in the Teaching of Manipulative Skills in Chemistry.* Unpub. M.Sc. thesis, School of Chemical Science, University of East Anglia.

PARLETT, M. & HAMILTON, D. 1972 *Evaluation as Illumination: a new approach to the study of innovatory programmes.* Occasional paper 9, Centre for Research in the Educational Sciences, University of Edinburgh.

PAYNE, V. G. 1932 The lecture demonstration and individual laboratory methods compared. *J. of Chem. Educ.* 9(5), 932-939, 1097-1102, 1277-1294.

PEARSON, K. 1894 Contributions to the mathematical theory of evolution. *Philosophical Transaction of the Royal Society.* Series A. CLXXXV, 71-110, Paper read Nov.16 1893.

PERRUSSEL, R. C. 1930 *A critical study of the value of the laboratory method versus the general class method in the teaching of physics.* Unpub. M.A. University of Kansas.

PHILLIPS, T. D. 1920 A study of notebook and laboratory work as an effective aid in science teaching. *School Review,* **20**, 451-453.

PRUITT, C. M. 1925 *An experiment of the Relative Efficiency of Methods of Conducting Chemistry Laboratory Work.* Unpub. Masters thesis, University of Indiana.

PUGH, D. B. 1927 A comparison of the lecture-demonstration and individual laboratory methods of performing chemistry experiments, as measured by non-standard objective tests. *High School Teacher,* **3**, 184-187.

RAINEY, R. G. 1965 The effects of directed versus non-directed laboratory work on high school chemistry achievement. *J. Res. in Science Teaching,* **3**, 286-292.

RAMSEY, G. A. & HOWE, R. A. 1969a An analysis of Research and Instructional procedures in secondary school science, Part I: Outcomes of instruction. *The Science Teacher,* **36**(3), 62-70.

RAMSEY, G. A. & HOWE, R. W. 1969b An analysis of Research and Instructional Procedures in secondary school science. Part II: Instructional Procedures. *The Science Teacher,* **36**(4), 72-81.

ROBERTSON, M. L. 1932 A study of the relative effectiveness of two methods of teaching elementary science. *Science Educ.* **16**, 182-187 (White 1943).

ROSSA, E. 1963 Referat: Das Experiment im Unterricht. *Chemie in der Schule,* **10**, 439-455.

ROWNTREE, D. 1974 *Educational Technology in Curriculum Development.* Harper & Row, London.

RUJA, H. 1954 Outcomes of lecture and discussion procedures in three college courses. *J. of Experimental Educ.* 22, 385-394.

SCOTT, V. G. 1929 *An experiment in the effect of the individual laboratory versus demonstration method on the pupil's final grade in general science.* Unpub. M.A. thesis, University of Washington.

SHORE, D. P. 1929 *Demonstration laboratory versus individual laboratory in teaching high school physics.* Unpub. M.A. thesis, George Peabody College for Teachers.

SHULMAN, L. S. 1970 Reconstruction of educational research. *Rev. of Educ. Res.* 40, 371-396.

SHULMAN, L. S. & TAMIR, P. 1973 Research on teaching in the Natural Sciences. In: Travers, R.M.W. (Ed) *Second Handbook on Res. of Teaching.* Rand McNally, Chicago, 1098.

SPEAR, E. B. 1915 Problems in the experimental pedagogy of chemistry. *J. of Educ. Psychology*, 6, 231-241.

STUIT, D. B. & ENGLEHART, M. D. 1932 A critical summary of the research on the lecture-demonstration versus the individual laboratory method of teaching high school chemistry. *Science Education*, 16, 380-391 (In Cunningham 1946).

SWIFT, J. N. 1969 *Research in Science Education 1948 through 1952.* Teachers College Press, University of Columbia, New York.

THORNDYKE, E. L. 1904 *An Introduction to the Theory of Mental and Social Measurement.* Teachers College Press, Columbia University, New York.

VAN HORNE, D. 1929 *An experimental comparison of demonstration and individual laboratory methods in high school chemistry.* Unpub. Master's thesis, University of Southern California, Los Angeles.

WALTER, C. H. 1926 *A comparative study of the teacher demonstration and the individual laboratory methods in physics when the time saved by the former method is given to drill work.* Unpub. Master's thesis, University of Chicago (Keiser 1933).

WALTER, C. H. 1930 The individual laboratory method of teaching physics when no printed directions are used. *School Science & Maths.* 30, 429-432.

WARD, J. 1956 Group-study versus lecture demonstration method in physical science instruction for general education college students. *J. Experimental Educ.* 24, 197-210.

WHITE, J. R. 1943 *A comparison of the group-laboratory and the lecture-demonstration method in Engineering instruction.* Unpub. doctoral thesis, School of Education, University of New York.

WILEY, W. H. 1918 An experimental study of methods in teaching high school chemistry. *J. Educ. Psychol.* 9(4), 181-198.

WILKINSON, G. H. 1928 *A comparison of four methods of laboratory procedure in high school physics.* Unpub. Master's thesis, University of Southern California, Los Angeles. (Keiser 1933).

YAGER, R. E., ENGLEN, H. B. & SNIDER, B.C. 1969 Effects of laboratory and demonstration methods upon the outcomes of instruction in secondary biology. *J. Res. in Science Teaching*, 6, 76-86.

YOUNG, J. E. 1949 *The Ability to Draw Inferences from Science Experiments.* Unpub. D. Ed. thesis, University of Glasgow.

Studies in Science Education 9 (1982), 147-160

Research Notes

TRAINING TEACHERS TO COPE WITH THE 'REALITY SHOCK'*

TH. WUBBELS, H. A. CRÉTON, H. P. HOOYMAYERS, A. J. C. D. HOLVAST
Teacher Training and Educational Research Group of the Physics Department,
State University of Utrecht, Holland

SUMMARY

This paper describes research on the early experiences of young teachers at the beginning of their career. These experiences are often referred to as the 'reality shock'. In this article we show where the roots of this reality shock may lie and we describe some starting points for teacher training courses that are designed to help young teachers cope with the reality shock and its consequences.

Finally we indicate how we mould these starting-points into concrete programmes in our pre-service training for physics teachers and in our in-service training for new teachers.

1. THE REALITY SHOCK

After completing their studies many young teachers start their professional career full of ideals. At the beginning of their career ideals such as acting democratically and trying to keep in touch with the experiences of pupils are important to young teachers (Müller-Fohrbrodt, 1978). This idealism is generally mingled with some fear of the unknown teaching situation. A teacher who initially has no worries may pass through various stages of concern. We are of the opinion that teachers cannot begin to think about the teaching situation and the pupils until they have conquered their own fears and are no longer concerned about self-preservation (cf. Fuller and Bown, 1975).

Müller-Fohrbrodt (1973) mentions that the first emotional experiences in the teaching situation make many young teachers depressive and irritable. These experiences make the young teachers worry about whether they will ever make good teachers. The concern and experiences are part of what in the German literature is referred to as 'Praxisschock' (e.g. Müller-Fohrbrodt, 1978; Hinsch, 1979).

---

* The authors are greatly indebted to Miss Sheila McNab for linguistic advice on the presentation of this paper.

This is what the English know as the reality shock. Research results of Kuntz (1973) suggest that this reality shock is much more apparent with teachers than with graduates who make a career in, for instance, industry. Several investigations and our own results confirm the existence of a reality shock (e.g.Müller-Fohrbrodt, 1978; Hinsch, 1979; Iberer, 1974; Koch, 1972; Vakgroep Natuurkunde-Didaktiek, 1978). One way to prove that the reality shock exists is to observe the change of attitudes in young teachers. Müller-Fohrbrodt and Hinsch found in German studies that the attitudes of students become much more progressive during teacher training; but when new teachers start their professional career their attitudes become much more conservative.

By 'more conservative' these authors mean e.g. putting more emphasis on control and discipline and being less inclined to support innovations in teaching. In a Dutch study (De Wijs, 1980) no indications were found that ideas about standards and values became more conservative, but there was an indication that after young teachers start their career they think that maintaining discipline is much more important than they did before they started.

We carried out a study among 240 young physics teachers (Vakgroep natuurkunde-didaktiek, 1978) and found that 60% of the young teachers were not very satisfied about the lessons they taught. The most difficult problems were how to maintain discipline, how to use teaching methods and how to build up a good relationship with their pupils. The teachers agreed that their own behaviour had become more authoritarian. If they could make a new start they would act in a stricter manner. Finally we mention a Dutch study by Olgers and Riesenkamp (1979) who found that after 1½ years of teaching practice young teachers have aligned their views with those of many of their colleagues in the school. Then they have lost much of their willingness to accept innovations. In our most recent study among young teachers we found that 60% of them faced severe problems in maintaining discipline (Vakgroep natuurkunde-didaktiek, 1980).

Some of the factors that may influence the change of attitude are

- the gap between school practice and theories taught at the teacher training institutes, and
- the (more) 'conservative' attitude of experienced teachers in the schools (Müller-Fohrbrodt, 1978).

In our view an important point which is not stressed often enough in the literature is that the new teacher is not able to mould his behaviour adequately to meet the different demands of his environment. This is particularly true as far as his interpersonal behaviour in relations with pupils is concerned. We shall describe the difficulties the teacher experiences in constructing his teaching role, because of the different demands made upon him by his environment and his ideals.

2. ONE OF THE MAIN CAUSES OF THE REALITY SHOCK

Our suggestions for teacher training are based upon a model that describes the origin of the reality shock. The model stresses the importance of the concept of role-construction (Klose, 1971; Gross, 1958). Different forces influence the construction of the professional role of the young teacher. First we shall describe the various elements that are important in shaping the role of a teacher.

2. 1. Personality

The interpersonal behaviour that suits a teacher best in his relationship with pupils depends very much upon his personality (e.g. Combs, 1974). This is true not only with regard to his behaviour in lessons but with regard to all his behaviour. (Leary, 1957).

A teacher who e.g. finds it easy to manage other people finds it easy to use teaching methods like lecturing and classroom discussion where he plays a central role, whereas a teacher who is a more modest person is more successful when pupils work in groups or independently. The teacher can then help the pupils individually. The former type of teacher will more readily use the styles that Galton and Eggleston (1979) call Informing and Problem-Solving and the latter type of teacher will more easily use the Enquiring style. A teacher who displays many varieties of a certain type of behaviour outside the classroom, in situations in which he feels safe, often is able to use this type of behaviour inside the classroom as well.

If in the classroom, when he feels unsafe, a teacher tries to use behaviour which he finds very difficult to adopt, then he is likely to behave in a stereotyped and forced manner. This behaviour usually is not adequate to meet the classroom situation. It is important that the teacher be himself in the classroom. This means that the young teacher will have to act in a way that suits his character, adopting the behaviour that comes to him most easily. Moreover, he will perhaps have to broaden his behaviour repertoire in accordance with his capacities and his personality. Interpersonal skills such as judging, stimulating, guiding, entering into pupils' thoughts, forbidding, showing respect, giving pupils ample scope, are all essential tools of the teacher's trade.

2. 2. Ideals

A person who starts teaching has been in the position of a learner for almost 20 years. That is why in his first lessons a young teacher has little difficulty in identifying himself with the pupils. It is difficult for him to feel like a teacher. A new teacher is inclined to think that many of the experienced teachers who are regarded as very good by their colleagues and pupils are in fact poor teachers.

The thoughts of young teachers are very much influenced by the way in which they experienced their own education. Matters such as acting democratically and taking personal responsibility are of great importance to them and they dislike authority and the standard methods of maintaining discipline. That is why they very often cherish the ideal of having a relationship with pupils that is based upon equality and kindly understanding.

For many people there is a relationship between ideals and personality: they cherish ideals that are partly realizable in the light of the capacities that are linked with their personality.

2. 3. Environment

The behaviour of a teacher is affected not only by his personality and his ideals but also by factors in his environment, such as the subject being taught, the number of pupils in his classes, the time-table, etc. Other important factors affecting the teacher are the expectations of what Sullivan (1953) calls 'significant others' such as his colleagues, the pupils and the Head of the school. These people all have very different expectations. Colleagues for instance expect the young teacher to behave in a stricter and more authoritarian manner than pupils expect.

2. 4. Role construction

The role of the young teacher is gradually constructed under the influence of the expectations of others, his own ideals and his own personality and it is this role which ultimately defines his classroom behaviour (fig. 1).

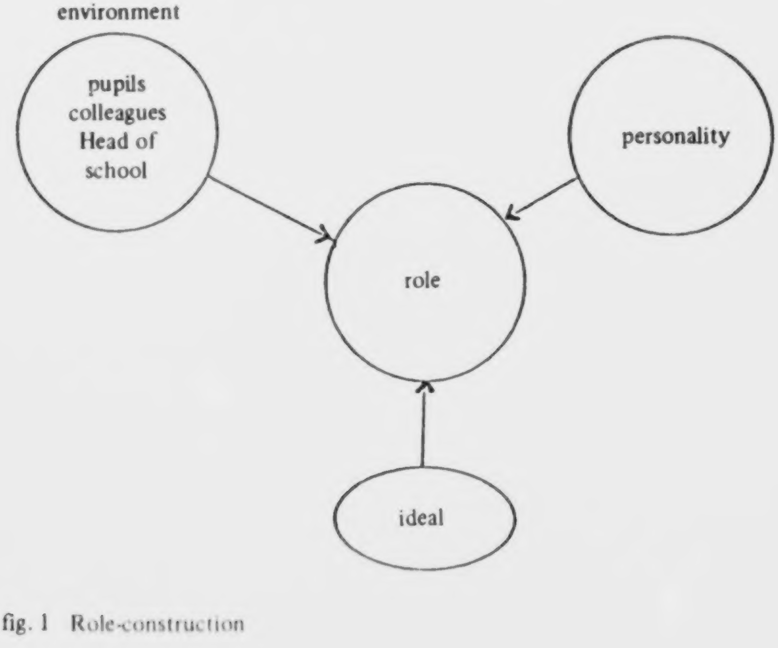


fig. 1 Role-construction

The young teacher will have to find a balance between the wishes and expectations of others and his own capacities. He will have to create his own professional role as a teacher. This professional role will be a compromise between the demands of others and his own feelings and needs (Buckley, 1968). Very often his own wishes have little in common with the expectations of colleagues and pupils. Furthermore, according to our experience the young teacher often does not have the personal capacities (especially as far as interpersonal behaviour is concerned) required to mould his ideals into concrete behaviour: there is an ambivalence in the young teacher himself because his ideals and his personality make different demands on him. Finally he has to cope with the different expectations of his colleagues, the school head and the pupils.

As a result of being pulled in so many directions and as a result of not being able to behave adequately the young teacher may feel very uncertain about his role. These feelings can cause severe stress. The stress that the young teacher experiences in finding his role is in our opinion one of the main reasons for the reality shock. The shock arises because the young teacher is confronted not only with the difference between his own wishes and the expectations of his colleagues, but he also becomes aware of his own inability to mould his ideals and wishes into concrete behaviour. Very often young teachers try to survive by adopting teaching methods such as lecturing, whereby the class can be handled more centrally.

This change in behaviour will often be accompanied by a change in attitude. Ideals such as treating pupils as peers are abandoned and the young teacher becomes more 'conservative'. Of course the school structure and school climate also have a marked influence on the behaviour and attitude of the young teacher. That is why it is often suggested that the reality shock can be prevented by changing the school system. We think that if one wants to help the young teacher preserve his ideals a great deal can be done in the pre-service and in-service training period.

3. PRINCIPLES OF A TRAINING PROGRAMME

We mention three of the principles of our training programme.

- Many young teachers in Holland have problems in maintaining discipline. That is why pre-service and in-service training should help young teachers to establish an adequate relationship with their pupils. Because teaching is a very complex activity the causes of these problems can be manifold. There is not much point in discussing which teaching abilities are particularly important for teachers. The only thing we can say is that a young teacher needs to have a reasonably good relationship with his pupils. If he does not, none of his other abilities is of relevance, because the atmosphere in the classroom is so bad that he simply cannot show these abilities. So teacher training should help young teachers to establish an adequate relationship with their pupils.
- In our training programme emphasis is on the behaviour of the young

teacher, as it is this which can serve as an instrument to change inadequate classroom situations. The young teachers themselves often try to find reasons outside themselves for giving poor lessons. For instance they blame the book they are using, the subject matter, the time of the day, the age or the behaviour of the pupils. We do not deny that these factors have a marked influence on the classroom atmosphere. But the young teacher cannot really influence these factors. What he can influence is his own behaviour. This is why it is so important for the young teacher to learn that his own behaviour is something he can manipulate. Teacher training should therefore help young teachers to use and to broaden their repertoire of interpersonal behaviour in classroom situations.

This interpersonal behaviour can be observed with the help of an instrument we have developed following the work of Leary (1957). The instrument describes the interpersonal traits of personality in classroom situations on the basis of classroom observations.

– Another aim of our training programme is to help the young teacher to contribute consciously to the construction of his role.

4. PRE-SERVICE TRAINING

An important consequence of the reality shock is that the young teacher tries to survive by maintaining strict discipline. Often this teaching style becomes an integral part of his behaviour, even in the long term, and therefore his development is blocked. Pre-service teacher training can help new teachers develop their teaching beyond this point, but if it is to be successful the student teacher must be given complete charge of his pupils (in spite of the presence in the classroom of, for instance, a mentor). Furthermore we think that teaching theory and teaching practice should be closely integrated into the teacher training course. This means for instance that the theory of teaching methods should be taught while students are actually having the experience of using these methods. These experiences should be used as an important input in the theory sessions during teacher education at the university or at an institute of education.

To diminish the reality shock in our training course (that lasts only four months) we pay a great deal of attention to the development of a personal teaching style, role construction and techniques for survival.

4. 1. The development of a teaching style that suits the individual best

The student should develop a teaching style that suits his personality as well as possible. Behaviour that does not suit his personality is likely to be strained and stereotyped. If he displays behaviour that fits his personality he will be better able to vary his behaviour according to the classroom situation. If he is to improve his performance in difficult situations the student must realise that his own behaviour is the major instrument with which classroom situations can be changed.

Of course we do not aim at helping students develop all possible teaching styles. We help those new teachers and students who want to create classroom situations and a classroom atmosphere in which pupils will feel at ease and want to learn.

To be able to develop a teaching style of his own the student must feel safe in the training situation. That is why we teach students to give each other feedback and thereby help each other. This is also the reason why the tutor and supervisor do not take part in assessing the student and why they do not give him a mark or grade when he completes his training.

We help students to develop their own teaching style in a number of ways.

4.1.1. *Confrontation with many alternatives*

We confront the students with many experienced teachers so that he later on will not merely copy the teaching style of his own teacher-supervisor, but will try to find a style that suits him best. In discussions we try to find many alternative solutions for problems the students face so that they can choose the solution that best fits their personality.

4.1.2. *The student group as behaviour model*

In Holland teachers-to-be spend only 80 hours with pupils in classrooms. We also use the student group to train the students to adopt a behaviour pattern that best suits their personality. To this end we use the technique of role-playing and often feedback on behaviour is given in group discussions.

4.1.3. *Strong and weak points in classroom behaviour*

In all discussions after a lesson we try to make the student analyse his own behaviour. We try to help him make use of the strong points in his behaviour in subsequent lessons. We discuss how he can improve (or avoid) his weak points in a way that best fits his personality. Sometimes the student can practise this in a micro-teaching situation. Such a situation gives him the chance to try to use his strong points or avoid his weak ones when teaching a small group of pupils for a short period.

4.1.4. *Written reports*

Students must be shown how important what they learn is for the development of their own teaching style. To make this clear we make use of reports written by the students.

For instance, they have to write a report half way through their training period. This report is discussed with fellow students and the institute tutor. In these discussions we help students to mould learning aims into concrete behaviour.

4.1.5. *Discussions with pupils*

Often teaching in the classroom situation is so complex that it is very difficult for the student to find his own style. We therefore stimulate him to talk as much as possible to individual pupils, not only in the classroom when the teaching method allows it, but also outside the classroom. We even train him in interviewing pupils. We hope that in this less complex situation the student will learn a bit more about what he likes and what he does not like in teaching and therefore a bit more about his personal teaching style.

4.2. Role-construction

We think it is important that a student should know how a number of variables influence his role construction. The influence of his own personality on his role-construction has been dealt with in the previous section. In this section we shall describe how we try to analyse with a student the influence that his own ideals and the different expectations of pupils, colleagues, etc. have on his role-construction.

4.2.1. *Clarifying ideals and objectives*

The student observes many different teaching styles (e.g. the styles which Galton and Eggleston (1979) call Problem-Solving, Informing, Enquiring or styles that stress the social development of pupils) and many different types of teacher-pupil interaction in his training. In discussions at the institute we try to compare these styles and types and we try to relate them to teaching objectives and ideals.

4.2.2. *Moulding ideals and objectives*

The supervisor and institute tutor try to help students preparing lessons to incorporate their ideals into a teaching programme. They also discuss how the students should translate their ideals into concrete teaching behaviour.

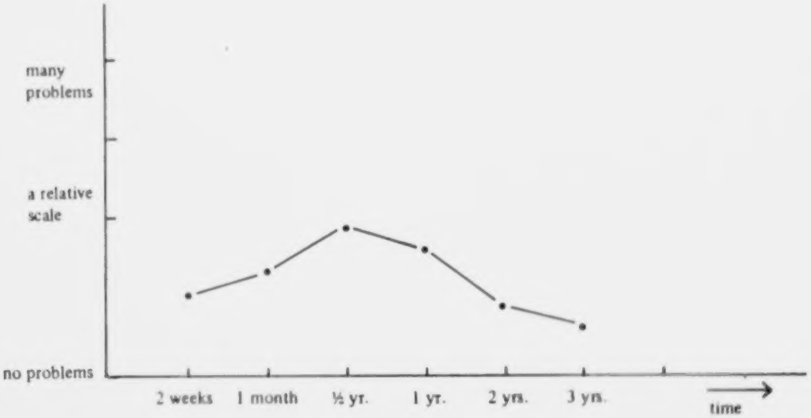
4.2.3. *Expectations of others*

Student-teachers should be aware what behaviour pupils, colleagues and school-heads expect them to display. We therefore ask students to have conversations with individual pupils or small groups of pupils. At the institute we train them to do this. The students also interview colleagues of the supervisor, the school-head or deputy head. Reports on these interviews are compared and discussed. Finally we have discussions at the institute in which we compare the expectations of pupils, colleagues and school-heads and try to relate these expectations to the students' own desires.

4.3. Techniques for survival

Our study, conducted among 240 young teachers, shows that nearly all of them had problems in maintaining discipline at the start of their career. After some months these problems come to a climax and then gradually diminish (see figure 2, Vakgroep natuurkunde-didaktiek, 1978).

fig. 2 Discipline problems



We know therefore that problems with discipline in the classroom are in most cases only temporary. On the one hand teacher training has to train students to face up to these problems and on the other hand it has to train them for the altered situation when these problems have been solved. In our pre-service training we do a number of things to help young teachers overcome their problems and yet maintain discipline in a way that does not destroy their ideals.

4.3.1. *The maintenance of discipline*

First of all we tell students that they will have discipline problems but that they are temporary if they themselves behave in an adequate manner. Often students do not want to maintain discipline. We stress that it is important to maintain discipline if students want to achieve their ideals later on.

We help students to cope with disorder in a way that best suits their own style. For instance, some students who have qualities of leadership can take strong disciplinary measures. Other students who find this very difficult or students who refuse to be leaders would in a similar situation do better to reorganise their lessons. For instance, it may be advisable for them to dispense with classroom discussion completely and concentrate on 'lecturing'. We work on developing adequate behaviour in disorderly situations in the way described in the section on the development of an individual style.

4.3.2. *Capacity for self-improvement*

To survive, the student-teacher must be able to improve his standard of teaching. This means being able to analyse his own lessons and being able to see how his behaviour influences the pupils. The student-teacher should be able to analyse what is going wrong and what is going well and what he as a teacher should change to ensure that the next lesson he gives will be better. That is why in discussions after lessons it is the student himself who has to do most of the evaluation of the lesson he has given. Gradually he becomes able to reflect on his lessons and thereby improve them.

4.3.3. *Meeting with young teachers with some experience*

At the end of the training course we arrange a meeting between the students and some young physics teachers who have followed our training course in previous years. These teachers answer the students' questions and they talk about their experiences as teachers, about their problems and the way they try to solve them, about their ideals and the way they try to realise them and about the way in which they have been able or unable to make use of their teacher-training experiences in practice.

Despite all our efforts it is impossible to prevent the student from encountering the reality shock. The training situation is too different from the actual situation in the schools. Three important differences are:

- When the student becomes a teacher there is a considerable increase in his responsibility with regard to persons (parents, staff) and matters (bad examinations, choice of books, sending pupils out of class, etc.) within the school as a whole.
- In the school the teacher has much more responsibility with regard to the micro-structure (e. g. more classes and more lessons).
- The student-teacher's feeling of insecurity increases as he is exposed to the authentic classroom situation (e.g. he is no longer under the guidance of a teacher whom pupils respect).

It does not seem to be a good idea to give the student in his training in the classroom too much responsibility too quickly because if the situation is too complex or too uncertain he is unable to learn much because he becomes concerned only with survival and self-preservation. The relation between the school and the institute would become bad because the quality of the student's lessons would be much lower. We agree with the suggestions of Heinen et al. (1979) on this topic of responsibility.

The new teacher is bound to have difficulty in maintaining discipline in school in spite of all the guidance he has received. It has been shown in our research project that discipline problems do not start to diminish until the teacher has taught for at least 300 hours and we cannot have a pre-service training-course that lasts as long as that. This is one of the reasons why we started our in-service training-programme four years ago.

5. IN-SERVICE TRAINING

As part of a research project we have developed an in-service training course for teachers in their first year of teaching. In this project the teachers are coached on the job. One of the aims of the project is to help young teachers to cope with the reality shock and its consequences (see e.g. Hooymayers, 1981). The training course consists of an interlinked series of guidance and supervision activities, which takes place on a voluntary basis. Each young teacher is under the supervision of an experienced teacher who keeps in contact with the institute. This 'mentor' must not be involved in deciding at the end of the school year whether or not the new teacher has reached the required standard; this to ensure that mutual trust develops between the mentor and the new teacher during the supervision period.

In the programme there are two persons to guide the young teachers, the mentor and a tutor from the institute. The latter draws up the programmes for the general meetings of the young teachers and for those of the mentors.

5. 1. Phases of the programme

The guidance period can be divided roughly into the following phases:

a. the logbook phase (lasting approx. three weeks)
b. the phase of lesson observation (lasting approx. four weeks)
c. the phase of individual guidance (lasting approx. five months)

The most important aim of the *logbook phase* is to make the new teacher aware of what is really happening in his lessons and to make him realize what part he himself plays in creating certain situations (which often he does not want). He writes down and describes in his logbook the matters that are important to him. During this phase the new teacher is helped by discussions with his mentor and other new teachers and by discussions in general meetings. Every two weeks these general meetings are attended by all the new teachers from the same school and a tutor from the institute. They come together to exchange experiences, discuss logbooks and mutual problems. During the *phase of lesson observation* the new teachers visit each other's lessons, and the mentor also observes the new teachers' lessons. All observed lessons are preceded or followed by discussions. Considerable use is made of video recordings of lessons given by the new teachers.

In this way the new teacher sees how others react to his teaching and he begins to have a much clearer picture of his own strengths and weaknesses. The young teacher also encounters alternative ways of handling problems and he sees that other teachers have the same problems as he has. Through discussion, the tutor and the new teacher try together to find ways of tackling and solving the problems the new teacher faces.

In the *phase of individual guidance* the mentor gives attention to the weak points in the new teacher's teaching. The guidance must necessarily be of a very individual nature because weaknesses vary so much from teacher to teacher.

If the new teacher is to derive any real advantage from this in-service training he will have to spend roughly four hours a week on guidance activities (over and above the time he needs for lesson preparation, etc.). The guidance programme is concerned mainly with helping the beginner to develop the abilities he needs for dealing with initial problems. Our project has shown us that a beginner's success depends largely on:

- his relationship with pupils;
- his knowledge of his own strengths and weaknesses in the classroom situation;
- his ability to deal adequately with disturbances in the classroom atmosphere;
- his methodological/didactical skill;
- his ability to analyse classroom situations under the influence of his own behaviour, the behaviour of the pupils and their effect on each other.

5. 2. Guidance activities and role-construction

In the logbook phase the young teachers write reports of their lessons. The aim of discussing these reports is to make the young teachers aware of the part they themselves play in creating classroom situations they or their pupils do not like. In each discussion emphasis is on the teacher's behaviour and the fact that it can be manipulated. There is also much emphasis on clarifying the desires, ideals, standards, values and expectations of the young teacher with regard to the classroom situation.

Finally we make the young teacher describe his own behaviour in a detailed way. In the general meetings emphasis is on the different expectations and demands of the environment. These demands become more and more sharply defined and the behaviour of the teachers under the influence of these demands can be better understood.

These meetings give the teacher what we call an emotional backing: the other young teachers and the tutor are an important reference group where the young teacher feels safe and cared for. This group can support the young teacher when he wants to do things that contradict the expectations of colleagues. Finally the young teacher can in these meetings measure his own achievement against that of others.

By observing lessons and having discussions with the young teacher the tutor and mentor first try to explain to the young teacher how he is shaping his role. If necessary the mentor and young teacher together try to find out what is wrong in the role-construction. Only when this has been done do we start finding new alternative behaviour that better suits the classroom situation and the personality of the young teacher.

In order to help the young teacher learn adequate behaviour the mentor stimulates him to produce his own alternatives. Sometimes the mentor makes suggestions, but not too often. To make it easier for the young teacher to succeed in adopting his new behaviour pattern, an attempt is made to create situations in which the young teacher feels safe. This is because in safe situations his repertoire of behaviour is at its most extended. Safe situations can mean for instance small groups, being with pupils he likes most, being in classes where the atmosphere is best or using his favourite teaching method. The learning of new behaviour is based upon the understanding of the effects of behaviour and upon the reinforcement of slight changes in the 'right' directions.

We try to make the young teacher understand what inadequate behaviour, such as constantly trying to shout down the commotion, leads to. We propose instead a slight change, if possible first in safe situations. Slight can mean that the behaviour is only slightly different from normal (for instance the teacher makes short pauses after asking questions) or that the teacher behaves differently only for a short period (e.g. waiting for silence at the beginning of a lesson). When new behaviour has been tried the young teacher is given feedback. The mentor emphasises positive change by means of external reinforcement. Also the teacher's internal reinforcement is strengthened when the mentor points to positive changes in the classroom atmosphere. If the young teacher does not succeed in changing his behaviour we propose an even smaller change in his behaviour or try to find a situation that is safer.

5. 3. Research results

Some research has been carried out on the results of this kind of in-service training by means of questionnaires, observations and interviews. A first analysis shows that new teachers found that:

- guidance increased their self-confidence because they felt they received support from experienced teachers (or from institute tutors) and because they saw that other new teachers experienced the same type of problems and were in fact fellow-sufferers. This made them feel they were not alone with their problems.
- guidance made them realise their weak points and strong points in their classroom behaviour and made them learn to use their strong points more effectively.
- guidance made them overcome beginners' problems sooner than if they had to solve these problems on their own.
- the climate in the school changes so that problems teachers have with the maintenance of discipline can be discussed.

These are only preliminary results from the guidance programme for 60 new teachers. A much fuller report about the results is available in Dutch.

6. CONCLUSION

Although we are still at an orienting stage in our research and in the guidance programme in pre-service and in-service training, we feel we are on the right course. We think we can help students and young teachers to face up to and to overcome the reality shock. Essential to our approach is that our pre-service training integrates fully students' experiences in teaching practice with general didactics and the didactics of physics. In our in-service programme the main emphasis is on the young teachers' ability to build up an adequate relationship with their pupils.

REFERENCES

BUCKLEY, W. Society as a complex adaptive system. In *Modern Research for the Behavioral Scientist*. Chicago: Aldine Publishing Company, 1968.

COMBS, A. W. e.a. The professional education of teachers. *A Humanistic approach to teacher preparation*. Boston: Allyn and Bacon, 1974.

FULLER, F. F. and BOWN, O. Becoming a teacher. In Ryan K. (ed), *Teacher Education*. The 74th Yearbook of the NSSE, Chicago. University of Chicago Press, 1975.

GALTON, M., EGGLESTON, J. Some characteristics of effective science teaching, *European Journal of Science Education*, 1 (1979), 75-87.

GROSS, N. M. e.a. Explorations in Role Analysis: *Studies of the School Superintendent Role*, New York, 1958.

HEINEN, K. e.a. *Lehrer ausbilden, aber wie?* Düsseldorf, Pädagogischer Verlag, Schwann, 1979.

HINSCH, R. *Einstellungswandel und Praxisshock bei jungen Lehrern*. Basel: Beltz Verlag, 1979.

HOOYMAYERS, H. P. Teacher training and curriculum development in the Physics Department of the University of Utrecht. *European Journal of Science Education* (in press) 1982.

IBERER, G. *Lehranfänger und Schulwirklichkeit*. Erziehung und Unterricht, 8 (1974), 456-469.

KLOSE, P. *Das Rollenkonzept als Untersuchungsansatz für die Berufssituation des Lehrers*. Kölner Zeitschrift für Sociologie und Sozial Psychologie, 23, 1971, blz. 78-97.

KOCH, J. J. *Lehrstudium und Beruf*. Ulm, 1972.

KUNTZ, K. M. *Zur Sociologie der Akademiker*. Fortbildung in 16 akademischen Berufen. Stuttgart: Enke, 1973.

LEARY, T. *An interpersonal diagnosis of personality*. New York: Ronald Press Company, 1957.

MÜLLER-FOHRBRODT, G. *Wie sind Lehrer wirklich?* Stuttgart, Klett, 1973.

MÜLLER-FOHRBRODT, G. e.a. *Der Praxisschock bei jungen Lehrern*. Stuttgart: Klett, 1978.

OLGERS, A. J. and RIESENKAMP, J. *De onderwijskundige voorbereiding van aan-staande leraren*. Haren: RION, 1979 (in Dutch).

SULLIVAN, H. S. *The interpersonal theory of Psychiatry*. New York, 1953.

VAKGROEP NATUURKUNDE-DIDAKTIEK. *Inventariserend onderzoek onder beginnende natuurkundeleraren*. Utrecht, R.U. -Utrecht, 1978 (A research study among young teachers) (in Dutch).

VAKGROEP NATUURKUNDE-DIDAKTIEK. *Begeleiding beginnende leraren*. Utrecht, R.U. -Utrecht, 1980 (A research study in the field of guidance of young teachers) (in Dutch). (Paper presented at the annual meeting of the Dutch Education Research Association).

VAKGROEP NATUURKUNDE-DIDAKTIEK. *De beginnende leraar, zijn klas en zijn begeleiding*. Utrecht, R.U. -Utrecht, 1981. (A theory on the position of young teachers, in Dutch).

WIJS, P.de. *Attitude veranderingen ten aanzien van opvoeding en onderwijs van jonge leraren in de beginfase van hun beroepspraktijk*. (1980) (Paper presented at the annual meeting of the Dutch Educational Research Association).

Studies in Science Education 9 (1928) 161-163

SUPPLEMENTARY LIST OF THESES AND DISSERTATIONS SUBMITTED FOR HIGHER DEGREES IN BRITISH UNIVERSITIES 1979-80

The information below is additional to the list of theses and dissertations completed during sessions 1978-79 and 1979-80, printed in Volume 8, *Studies in Science Education,* 1981, pp.106-117. Theses and dissertations completed in sessions 1980-81 and 1981-82 will be listed in Volume 10, *Studies in Science Education,* to be published in 1983.

The teaching and learning of biology, environmental science and geology.

1. An investigation into the effects of using interactive visual imagery on map interpretation tasks among first year middle school children.
   T. Hall Aston M.Sc. 1979
2. The development and current practice of environmental science teaching.
   T. Pellow Aston M.Sc. 1979
3. Geology and the core curriculum in science.
   R. D. Trend Keele M.Sc. 1979
4. The place of UCLES social biology 'A' level in the curriculum.
   P. J. Rance Keele M.Sc. 1980

The teaching and learning of chemistry

5. An inquiry into the mental processes involved in representing chemical reactions by balanced symbolic equations by adolescents.
   J. Thomas Aston M.Sc. 1980
6. Some problems associated with the teaching of the modular orbital theory and the implications for the school-university interface.
   G. D. Lloyd Keele M.Sc. 1980
7. Implementing the Nuffield 'A' level G.C.E. chemistry metallurgy special study: a case study.
   H. E. G. White Keele M.Sc. 1980

The teaching and learning of physics

8. A study of the difficulties encountered by sixth-form students in understanding electrostatics.
   J. R. Bowler Keele M.Sc. 1980
9. The holding of concepts and misconceptions in physics by graduate scientists who are training to teach.
   J. A. D. Healey Keele M.Sc. 1980

The teaching and learning of mathematics

10. An enquiry into sex differences and other factors involved in a spatial ability mathematical task.
G. Griffiths Aston M.Sc. 1976

11. An enquiry into sex differences in abilities, interests and person perception with special reference to spatial and mathematical ability and the replication of a spatial test.
D. W. Cole Aston M.Sc. 1978

12. Imagery strategies in solving algebraic equations.
C. Mills Aston M.Sc. 1979

13. An investigation into modality preferences in the solution of mathematical problems.
D. Hooper Aston M.Sc. 1980

14. Individual differences in mathematical performance among school children.
P. Howlett Aston M.Sc. 1980

15. Problem solving in mathematics
J. F. Feakins Keele M.Sc. 1979

16. How secondary school children check their work in arithmetic: an exploratory study.
J. Lee Merida Keele M.Sc. 1979

17. A school-based study of the learning and understanding of ratio/proportionality by pupils of average mathematical ability at 10+, 12-13 and 15-16.
I. Dalrymple-Alford Keele M.A. 1980

18. An investigation into the effect of science instruction on lower secondary school pupils' performance in mathematics.
D. Fishwick Keele M.A. 1980

19. An investigation into the understanding of intuitive concepts of chance in pupils in the age range 12-15 years.
O. K. Kitheka Keele M.Sc. 1980

20. An exploratory study of children's understanding and use of diagrams in mathematical situations.
G. A. S. Mandara Keele M.Sc. 1980

21. An investigation of the ability of children to provide rough estimates to numerical calculations.
R. Morris Keele M.Sc. 1980

22. An attempt to identify and improve the range of procedures used by children to check work done with an electronic calculator.
I. Thompson Keele M.Sc. 1980

Girls and science (see also 10, 11)

23. Girls and science: an investigation based on the semantic differential.
C. Hesketh Aston M.Sc. 1978

Other studies

24. An investigation into the uses of microcomputers in schools with special reference to the early development in the City of Birmingham.
R. Brown Aston M.Sc. 1980

25. Piagetian reasoning as predictive of academic performance of engineering craft students in first year further education: a multivariate analysis..
J. Ferla Aston M.Sc. 1978

26. Independent learning in Further Education.
W. A. Courtney Keele M.Sc. 1979

27. The vocational education and training of technicians and engineers.
I. Clements Keele Ph.D. 1980

28. Modes of information perception and transformation in science students.
J. N. King Keele Ph.D. 1980

29. Innovative doctrine and practical dilemmas: a case study of curriculum translation.
J. K. Olson Keele Ph.D. 1980

RECENT RESEARCH GRANTS

Social Science Research Council

1. Micro-processors in schools.

The SSRC established a Working Group on Micro-processors in Schools in January 1980. In the light of the considerable public interest in the topic and the likelihood of government investment in developmental work, the Group was given the task of examining research needs in the area, especially in relation to educational and social computing aspects. Projects commissioned by the Working Group include:

Evaluative studies of the effects and effectiveness of micro-computer-based teaching in schools (HG 14/46/1/1)

£27,229, 28 February 1980–31 March 1981. J. R. Hartley and Professor K. Lovell, Computer Based Learning Unit, School of Education, University of Leeds.

Learning engineering science in school by computer (HG 14/46/1/2)

£31,140, 22 February 1980–28 February 1982. Dr. J. A. M. Howe, Department of Artificial Intelligence, Edinburgh University.

2. Accountability in Education

A Panel was established in 1977 to commission and take responsibility for a programme of research on Accountability in Education. Seven contracts have been issued, including:

Standards and performance in science (HG 14/41/4/1)

£27,380, 1 September 1979–31 January 1982. Professor P. J. Black and Dr. W. Harlen. Centre for Science Education, Chelsea College, University of London.

3. Equal Opportunities

The Social Science Research Council set up a joint panel with the Equal Opportunities Commission in December 1977 to take responsibility for commissioning research on the subject of equal opportunities. The panel chose 'Women and Underachievement' as the theme for its programme and projects granted support include:

An affirmative action project on the science achievements of schoolgirls (RB 20/10/13)

£32,000, 1 September 1979–30 August 1982. Dr. A. Kelly and Miss J. Whyte. Department of Sociology, University of Manchester.

This is an action research project intended to improve the achievement and attitude of girls to science, and to encourage girls to consider careers in science and technology. The project follows a cohort of pupils from the time they enter secondary school at eleven to the time they choose their options at fourteen. By means of intervention strategies such as visits to schools by women scientists, talks and discussions on career opportunities, the preparation of lesson material related to 'feminine' interests, compensatory science for pupils lacking background knowledge and workshop sessions with teachers, the project attempts to influence girls' attitudes, achievements and choices in science. There is also a more traditional component to the research concerned with the determination of the effect on girls of the image of science as a masculine subject.

Scottish Education Department

The Scottish Education Department has funded a research and development project in the teaching of science in the primary school.

The aim of the project is to provide advice on the use of the various curriculum materials and resources at present available from a wide range of sources. The project will also seek to establish the forms of support required by primary schools in developing the teaching of science as an aspect of environmental studies. Methods of giving guidance to schools in the preparation of teaching programmes will be tried out and evaluated.

Based at Moray House College of Education the project will run for three years and cost £50,000. It will be directed by Mr. Sinclair MacLeod, now of Moray House and formerly Principal Lecturer in Science at Callendar Park College of Education. He will be assisted by Miss Muriel Weir formerly Principal Lecturer in Science at Hamilton College of Education.

The project team will associate their studies with the work being currently undertaken in primary science across the country. To this end an advisory committee chaired by HMI Mr. J. Burdin will include representatives from primary schools, education authorities and colleges of education.

A NEW TEST INSTRUMENT

Test of Science-related Attitudes (TOSRA) Barry J. Fraser

Currently the promotion of favourable science-related attitudes is considered in many countries to be among the more important aims of science education. Consequently, science teachers, curriculum evaluators and educational researchers have need of a convenient and straightforward method for monitoring the progress of students or classes towards achieving attitudinal aims. TOSRA satisfies this need by providing a measure of seven distinct science-related attitudes which is suitable for group administration and which can be administered conveniently within the duration of a normal class lesson. It is intended for use in Years 7-10 of secondary schools.

TOSRA consists of 90 statements to which students express their degree of agreement by choosing from the responses Strongly Agree, Agree, Not Sure, Disagree and Strongly Disagree. Ten items assess each of the following seven scales:

Social Implications of Science
Normality of Scientists
Attitude to Scientific Inquiry
Adoption of Scientific Attitudes
Enjoyment of Science Lessons
Leisure Interest in Science
Career Interest in Science.

The test has been carefully developed through several versions which have been improved after obtaining comments from teachers, students and researchers and by performing item analyses with data obtained during field testing with over a thousand students. Subsequent administration of the final version of TOSRA to several thousand students in separate samples in three Australian states and in the USA has confirmed that the scales are highly reliable.

Materials consist of a set of Test Masters, a separate Answer Sheet, a transparent Score Key which permits easy hand scoring, and a Handbook which contains background information, statistics and instructions for administration and scoring. *After initial purchase, people in schools and other institutions may use the Test Masters to reproduce unlimited numbers of copies of TOSRA for use in their institution.*

1 Handbook 1 Set of Test Masters (4 sheets) 40 Answer Sheets 1 Score Key (transparent)	A$18.00
Handbook (separately)	A$ 4.50
Packet of Answer Sheets	A$ 6.00

The materials are available from:

The Australian Council for Educational Research Limited,
P.O. Box 210 Hawthorn
Victoria
Australia 3122. Telephone (03)818 1271

RESEARCH IN SCIENCE EDUCATION

Volume 10 of *Research in Science Education*, the annual publication of the Australian Science Education Research Association, is available, A$10, from:

Professor Colin Power, ASERA Executive Secretary,
School of Education,
Flinders University, Bedford Park, 5042,
South Australia, Australia.

Studies in Science Education 9 (1982), 167-176

Book Review

POLICY, PERCEPTIONS AND PRACTICE. NEW DIRECTIONS FOR SCIENCE EDUCATION

Gaalen L. Erickson
Department of Mathematics and Science Education, University of British Columbia

The Association for Science Education
Education through Science. Policy Statement
Published by The Association for Science Education, College Lane, Hatfield, Herts AL10 9AA. 1981, pp. 56, £1.75

Hugh Munby, Graham Orpwood and Thomas Russell (Editors)
Seeing Curriculum in a New Light. Essays from Science Education
Symposium Series: 12. O.I.S.E. Press. The Ontario Institute for Studies in Education, 252 Bloor Street West, Toronto, Ontario M5S 1V6. 1980, pp. 184, C$8.50

We are once again at a point in time when the role and goals of science education in our school system are being seriously examined from both inside and outside the science education community.[1] These periods of reflection and reconceptualisation, which seem to occur at twenty to thirty year intervals, are generally accompanied by a great deal of soul-searching and innumerable conferences and committee meetings, the products of which are eventually distilled into one or more position papers. It is not my intent here to place the current reconceptualisation exercises in an historical context, although that would certainly illustrate the recurrence of some of the themes which are discussed in both of the documents that are the subject of this review.[2] Nor do I want to argue that this cyclical revision process is an empty, self-serving or naive response of the science education community based on ignorance of the past. I share the view expressed in the Association for Science Education (ASE) policy statement that changes in social, political and economic conditions make changes in educational provision necessary. Rather, my intention is to examine the substance and form of one such attempt at reconceptualisation in the light of a set of articles whose expressed focus is to provide educators with alternative perspectives for viewing educational phenomena.

The two books considered in this review are both concerned with alternative visions of science education. The first, ***Education through Science,*** is a policy statement issued by the ASE and setting forth their perspective on future directions for science education. The second book, ***Seeing Curriculum in a New Light,*** is a collection of ten articles which aims to provide the educational community at large with an alternative set of analytical categories and research procedures through which to view educational events. Since these articles are framed in a science teaching context, it has special relevance to science educators.

There are some common issues and themes dealt with by the two documents which provide at least a *prima facie* case for examining them together in a single review article. *Education through Science,* being a policy statement, is orientated around prescriptions and recommendations for changing the practice of science instruction in schools. *Seeing Curriculum in a New Light* is concerned with the examination of educational practice using an alternative research style to that in current use, or, to make explicit the root metaphor used, to view educational events more clearly with the assistance of a new set of conceptual lenses. Many of the authors claim that by using these new lenses, both researchers and classroom teachers can obtain a much sharper image of typical events of practice, an image that is on the one hand different from that obtained by current research perspectives and on the other hand better suited to assisting practitioners with the task of implementing the sorts of changes envisaged by the ASE statement. Although the two books are clearly different in terms of their purposes and their primary audiences, if one construes the policy statement as the embodiment of a set of idealized practices then it may be a useful exercise to examine certain aspects and implications of this statement in terms of some of the analytical frameworks introduced in the other book. While this modest exercise is in no way intended to provide a critical test for these frameworks and concepts, it does provide a useful context in which to air the issues and arguments of both publications. Before engaging in this comparative procedure, a brief overview of the two publications will be presented to familiarise the reader with the purposes and approaches of each book.

Seeing Curriculum in a New Light is rather unusual among books of collected papers in that the editors have achieved a high degree of conceptual unity among the ten chapters. This unity is obtained in large measure from the acknowledged influence of a research programme initiated by Doug Roberts. One of the guiding methodological techniques of this programme (which is discussed explicitly only in the chapter by Mahung) was described in an earlier paper by Roberts and Russell (1975). This technique, which is referred to as 'conceptual analysis', entails three basic steps. The first consists of selecting a suitable 'theoretical perspective' in which to frame the problem area of interest. The second step, the construction of an 'analytical framework', requires an investigator to abstract from the theoretical perspective a series of essential questions or statements which are relevant to the educational events being studied. (Roberts and Russell referred to these statements as 'the clue structure'.) The final step consists of using these statements as a basis for making judgements about the educational phenomena under scrutiny. These judgements may range from a fairly straightforward congruency check (cf. Munby's list of features of 'Intellectual Independence') to more complex normative arguments (cf. Mahung's analysis of curriculum materials in terms of the 'adequacy of the curriculum as conceptualized by the developer'). This technique is really a way of making explicit how theory is used to inform our judgements about practice – an important element omitted in many research reports in the field. This highlighting of the inextricable relationship between theory and practice in educational inquiry constitutes then a major theme in the book. This relationship is examined in a variety of contexts ranging from the specific (e.g. the analysis of the teaching practice of individual teachers in chapters by Russell and Kilbourn) to the general (e.g. the positing of an overarching framework to view the 'theory-practice interface' by Roberts). Most of the articles attempt to focus on specific educational events, often using excerpts of classroom dialogue to illustrate the potential of their analytical framework and how it can be used to improve practice. In so doing they attempt to construct arguments and present evidence to support one of their major claims – 'the impotence of science-like theory for directly informing practice' – and hence establish the need for an alternative perspective of educational inquiry.

A second distinctive characteristic of this book is the extensive use of philosophical analysis as the theoretical perspective from which the analytical statements are derived to examine educational events. These philosophical analyses are drawn heavily from the various constructs introduced in the writings of Joseph Schwab, but also use other philosophical accounts ranging from Aristotle's distinction between the theoretic and the practical, to the writings of contemporary philosophers in the fields of education and science.

Their collective investment in exploring the usefulness of philosophical analysis as the primary source of conceptual lenses gives considerable clarity to their vision, but in so doing it also must necessarily restrict their field of vision. The focus in most of the chapters is on the notion of an analysis of the logical structure or provision inherent in particular educational phenomena. This includes, for example, the logical provision inherent in: teachers' discourse in science lessons (Munby's analysis of provision for 'Intellectual Independence'), the science curriculum as it pertains to the presentation to students of an 'implicit view of reality' (Kilbourn's chapter on World Views), arguments about competing curricular prescriptions or objectives (both of the chapters contributed by Orpwood based upon a view of 'practical reasoning'), and implicit features of curriculum materials which *may* affect what and how students learn (Mahung's chapter on the evaluation[3] of curriculum materials). In using the notion of 'logical provision' or examining the inherent logical structure of an educational event, most of the chapters focus upon only two of Schwab's four common-places (teaching and curriculum), while omitting the learner and the milieu as they are the only ones that can be readily framed in terms of a logical analysis. To say something of interest about the other two usually requires empirical as well as logical claims.

I am sure that most of the authors are aware of this limitation; in fact Roberts deals directly with the issue of the need for a teacher to possess a number of theoretical perspective (presumably from all four common-places) in deliberating about a particular course of action – a process that he refers to as 'informed eclecticism'. Also Russell and Kilbourn deviate somewhat from this pattern by focusing their attention upon the improvement of practice (in an inservice context and through clinical supervision respectively) rather than relying exclusively upon logical analysis. It should be emphasized that the general model, described above, could certainly be used to frame an educational event with a focus upon the learner or the milieu in addition to the two commonplaces dealt with in the present book. This extension to an examination of actual student outcomes and the social factors influencing those outcomes could help to assess the extent to which these other two factors may seriously compromise the results expected from a 'logical provision' analysis. The addition of an empirical dimension to their analysis would make an important contribution to the field of educational inquiry and further enhance our chances of improving practice. In summary however, although this book has provided us with a somewhat restricted field of view, I would argue that the authors have achieved their objective of presenting the educational community with an alternative way 'to see' curriculum events, and I think it will be of interest not just to educational researchers but to others concerned with educational practice.

The primary function of *Education through Science* was to provide for the members of the Association for Science Education and the public at large 'a definitive policy statement giving (the Association's) views on the direction science education should be taking in the next decade'. In acknowledging the current debate over the appropriate direction (i.e. purpose and broad aims of science education) the statement also explicitly recognises the need for a change in both policy and practice. The immediate concern is that the implementation of change be carried out in a 'restrained and logical manner . . . in the best interests of our young people' (not to mention members of the Association). What changes should occur and how can they proceed in a rational and orderly fashion? While the entire fifty-four pages are directed towards generating thirty-five specific recommendations and proposals which address these questions, several prominent themes and strategies emerge.

(1) The primary set of recommendations is based on the principle that science instruction ought to be viewed as a key component in any articulation of a general education. It should thus be treated as a *core* subject for *all pupils* at *all age levels* of schooling.

(2) This means increasing the level of provision for science instruction at the primary years, developing general, integrated science courses in the early

secondary years and expanding the range of options available to the 13 to 16 age group and the post 16 age group.

(3) The pedagogical implication of the commitment to science for all pupils is that teachers will have to adopt a much more flexible range of teaching strategies to work with pupils with a greater diversity of interests and backgrounds. In developing these new approaches a greater degree of teacher self-evaluation will be required.

(4) The resources and strategies required to implement these changes include: training teachers at the primary level to involve children in science studies, recruiting more teachers who are able to teach science from a generalist rather than a specialist perspective, developing effective programmes of inservice training and support facilities and finally establishing appropriate committees within the Association charged with the responsibility of co-ordinating efforts to implement these policies.

While this is obviously a very abbreviated and condensed version of the thirty-five recommendations in the policy statement, it does indicate the general thrust of the report. The reader should consult the original document for the specific recommendations and the extensive rationale and background arguments offered for them.

One of the first questions that ought to be raised for the international science education community is whether this document has anything of interest to say to educational jurisdictions outside the United Kingdom. Although it clearly addresses some context-bound issues (e.g. difficulties of compliance with a fairly rigid and independent examination system) the basic thrust of the statement – the provision of a general education in science for pupils of all ages and ability groups – and most of the issues derived from that position are certain congruent with the substance of the deliberations which are occuring in several other contexts with which this reviewer is familiar.[4]

The ASE document is the culmination of a lengthy process involving the distillation of wide ranging reactions and debate about several earlier position papers published by the Association. Notwithstanding the commendable efforts made by the Association to reach a position which would have widespread support among the rank and file of the teaching force, this reviewer forecasts some rather stormy weather ahead as steps are initiated toward the implementation of this particular vision of a general science programme for all pupils. This pessimism does not stem from a concern about the way in which the process of developing the statement was conceived and executed; on the contrary, the present document along with its immediate predecessor, *Alternatives for Science Education,* I consider to be among the best of available position papers on the current state of the field of science education. Rather it stems from a view provided by hindsight, complemented by a series of recent studies examining the net effect of the science curriculum reform movement of the sixties on American schools.[5] These studies, in particular the excellent series of case studies (Stake and Easley, 1978), suggest that the many difficulties generated by attempting to introduce significant curriculum changes into the school system stem from factors both external and internal to the classroom. Those that are external emerge from an inextricable mixture of structural constraints of social, economic and political origins.[6] These constraints, which tend to be accompanied by deep-seated beliefs about schools and their role in society, often operate in a tacit manner to influence decisions at all levels of the educational establishment ranging from the specific decisions taken by teachers in responding to unique classroom events to more general policy decisions made at the local or ministerial level. Those that are internal include teachers' perceptions of what it is that is most important to teach, their preferred teaching and evaluation strategies and their knowledge of both the background subject matter and of the new curriculum materials themselves.

The lesson we have learned then, from past attempts at serious curriculum reform is that curriculum displacement does not *reduce* to a series of logical implementation procedures once 'the product' is delivered by the developers. It is, rather, a very complex process of decision-making which is continually mediated by inputs from broad social factors in combination with those much more situation-specific factors which reflect the realities at the local district or classroom level. It is at this point of examining the Association's implicit or explicit strategies for implementing their curriculum reform package that one can turn to the various analytical schemes or frameworks outlined in *SCNL* for possible sources of enlightenment.

Perhaps the best place to begin is to examine the model of curriculum displacement which is reflected in the policy document. Russell's chapter on 'Teacher Education Research and the Problems of Change' may be of some assistance in this regard in that he discusses several different models of change and also demonstrates some of the external and internal constraints operative on changes in teacher behaviour. In the rational model, the predominant one used by the curriculum reformers of the sixties, the teacher is viewed as a 'rational adopter' of totally prepackaged curriculum materials. Hence there was at that time a great expenditure of resources on inservice courses, summer workshops and the like to introduce teachers to the new goals, approaches and materials of the new courses. When the specified changes did not occur, or were resisted in some way, teachers were then viewed as 'stone-age obstructionists' (Doyle and Ponder, 1977). An alternative model is that of teacher as a 'pragmatic skeptic' who evaluates changes against the potential consequences of trying to implement such a programme in his classroom.

Does the ASE policy document contain an underlying model of change or implementation? It seems apparent that it is this segment of the curriculum reform package which is most troublesome to the Association. They admit that in the past the implementation process has been left to others, but they seem to be dissatisfied with that stance in the present circumstances. The question is (to employ a favourite expression of both books): what provision is made by the Association for the realisation of these proposals? Even a cursory glance at the document will reveal that they are keenly aware of the role played by the classroom teacher in mediating and interpreting curriculum prescriptions. (This is really not too surprising given that the ASE *is* a teachers' organisation). Clearly the authors of *Education through Science* tend to view teachers as 'pragmatic skeptics' and they have outlined several strategies which might be utilized to persuade schools and individual teachers to reconsider the basic aims of science education, to adopt more flexible teaching procedures, and to consider alternative formats for course delivery. Hence one major implementation thrust aimed at the most important elements of the internal constraints recognises the necessity of ensuring that teachers have both an understanding of the proposed changes and the necessary resources required to act upon these proposed prescriptions. To this end they have promised to deliver a set of 'curricular models which will explore different strategies for achieving the proposals in this policy statement. It is intended that the models will serve as templates for school-based development programmes' (p. 9). Although they provide only a glimpse of what the substances of these curricular models or school development programmes might look like, at least there exists some indication of a master blueprint, albeit a somewhat sketchy one, for dealing with the main sources of internal constraints.

Unfortunately, the same cannot be said of their contingency plans for dealing with the external constraints. These are in fact conspicuous by their absence. While they are certainly aware of some of these factors and recognise the importance of attempting to involve or solicit support from external agencies – teacher training institutes, school examination boards, industry and institutions of higher education – the only visible means for obtaining the necessary cooperation from these agencies or at least minimising their potentially constraining effects on the reform process, is to seek some form of official liaison with these agencies. It may be claimed by some that more specific and active strategies have no place in a policy document; however, a failure on the part of the ASE to take aggressive measures to counteract the very powerful influence of these agencies could mean the likelihood of success would be significantly reduced.[7]

Let us return to the issue of whether the analytical frameworks developed in *Seeing Curriculum in a New Light* may be of any use in clarifying some of the issues raised in this policy document or to assist those charged with implementing them. Given the necessary generality of both the policy statement and these analytical frameworks, it is clear that the latter cannot be used to make specific claims or prescriptions about the issues raised in the former. At best, they may be able to provide an interpretative perspective which could allow for some new insights to be gained by those involved in translating this broad policy statement into practice.

At the very core of the implementation plan for soliciting the support of teachers, and one of the essential elements for overall success is, in my opinion, the proposed establishment of the school development programmes. It is at the school and teacher level, then, where the practical decisions will be made regarding the selection of the most appropriate 'curricular model', the way in which these models will be altered or modulated to suit the unique characteristics of the school or classroom, and the way in which these modified curricular packages will be subsequently converted into actual teaching manoeuvres. These decisions can be clearly subsumed under Schwab's notion of 'practical deliberation' which implicitly permeates many of the *SCNL* articles and is central to Roberts' notion of 'informed eclecticism' discussed earlier. In constructing a general framework to analyse the roles and constraints operative at both the developer level and teacher level, he advances the notion of a 'developer-teacher interface'. The upshot of Roberts' analysis is that the developer's idealised conceptions of science education events cannot 'speak directly to the particularities of a unique science education event' (p. 75), and hence it is a logical necessity for teachers to modulate curricular prescriptions for use at the classroom level. To the extent that the Association is already aware of the prominent decision-making role of the teacher, this revelation may not contribute much to their implementation plans (other than to provide some logical support for their decision to establish school development programmes). The aspect of Roberts' article which may be of more instrumental value is his treatment of how one could make explicit the underlying assumptions (about the subject matter, the learner, the teaching conditions and the societal context) of curriculum materials. This portrayal of 'idealized science education events', as Roberts calls it, would be a most useful feature of the curriculum models in preparation by the Association as they would provide valuable information to teachers when deliberating about the choice or the adaptation of a given model.[8]

Other chapters in the book which deal with topics that may be relevant to this deliberation process are Mahung's discussion of the analysis of curriculum materials and Orpwood's two chapters on the logical structure of educational objectives. Even though the chapter on curriculum materials has the promise of delivering some very specific guidelines for selection between competing curricular packages, its lack of specificity is a serious shortcoming. For example, there is a very brief discussion of an unpublished paper on an analysis of some parts of the Nuffield 'O' Level Chemistry Project, but no indication whatsoever of any methodological procedures or substantive results. The two chapters on educational objectives draw upon a model of practical reasoning based on the work of Gauthier that Orpwood uses to analyse arguments advanced in support of a particular objective or set of objectives in science education. In one chapter the potential of the model is illustrated by generating and analysing the value premises and the empirical premises that were used in an argument to defend the teaching of science as enquiry. Given that one of the practical tasks which may be faced by local development centres is the analysis and selection of competing educational aims, then this model for analysing educational arguments might be of some assistance.

In addition to the role it is envisaged these school development centres will play in mediating curriculum inputs, they would also be linked to the continuing process of staff development and training. In this latter context, the chapters by Russell ('Developing Teachers' Analytical Skills') and by Kilbourn ('Ethnographic Research and the Improvement of Teaching') are particularly appropriate since both deal with the issue of helping teachers to become more reflective (or 'self-evaluative' in the language of the ASE statement) using an inservice context and clinical supervision techniques respectively. While both of these articles embed their analyses in a general discussion of current controversies in the educational research literature, this does not detract from their clear focus, accentuated with specific examples, on the problems of improving practice at the classroom level.

In summary, these publications focus upon aspects of some of the major problems facing the science education community in the years ahead and regardless of one's specific situation or country, the issues are presented in sufficient breadth so that those who are actively involved, or simply interested, in science education at any level would profit from reading them. If the ASE can indeed obtain the necessary resources and can succeed in persuading the science teachers of Britain that this policy statement represents a viable perspective of what their science classes ought to look like in the 1990's, not just the pupils, but all of us will profit from their vision and hard work.

FOOTNOTES

1. In the past five years we have witnessed a large number of studies, conferences and policy statements on the 'state' of science education. The ASE document being reviewed is the culminating statement based upon a series of position papers and reports by both the Association and governmental agencies, beginning in the mid 1970s. Likewise, in the United States and Canada a number of studies and reports have addressed the issue of the appropriate future direction for science education. A summary of the American response is described in *Project Synthesis* (Harms and Kahl, 1980) while a major Canadian study is currently under way (Orpwood, 1980).
2. There are several texts that have examined curriculum change in science education from an historical perspective. For example, in the U.K. Waring (1979), Jenkins (1979) and Layton (1981) have all discussed different aspects of the social influences upon science education policy and curriculum. In a somewhat different approach, Roberts (1978) has identified over-arching 'curriculum emphases' which have served as the orienting frameworks for the development of science curricula.
3. While Mahung refers to his treatment of the issues as an evaluative process I would question this claim. He seems to adopt a framework for evaluation which his article attempts to criticise – the early Tylerian notion of evaluation as a procedure of comparing intents with outcomes (or, in Mahung's instance, potential outcomes). When, in referring to a specific study, the author indicated that 'the purpose (of the study) was not to pass judgment on the adequacy of the project', it seemed clear that Mahung is engaged in an analytical rather than an evaluative exercise.
4. Most notably these contexts are the United States, where both the National Science Teachers Association and the National Science Foundation have been engaged in deliberations about science curriculum changes for several years, and Canada, where many of the ten provinces are either currently engaged in curriculum revision projects or have just recently completed one.

5. These studies, and the reactions and interpretations of them by various interest groups ranging from teachers' organisations to industry, are summarised in Yager (1981).
6. Layton (1982) has examined some of the assumptions which are made (and some that ought to be) regarding the current debate about the inclusion of Science, Technology and Society studies in the science curriculum. In so doing, he illustrates the potential role of political and psychological constraints in the context of curriculum change.
7. One of the prominent features of the British educational system is the extent to which the external examination boards 'drive' the curriculum-in-use and to that extent must be considered as one of the most important external constraints in the British context.
8. This type of analysis is anticipated to some measure in the ASE publication *Alternatives for Science Education* (1979) where existing curricula are analysed in terms of some of these assumptions. The authors go on to propose three different curriculum models based upon perceived implementation constraints.

REFERENCES

ASSOCIATION FOR SCIENCE EDUCATION (1979). *Alternatives for Science Education. A consultative document.* Published by Association for Science Education, College Lane, Hatfield, Herts.

DOYLE, W. & PONDER, G. (1977). The practicality ethic in teacher decision-making. *Interchange*, **8** (3) 1-12.

HARMS, N. & KAHL, S. (1980). *Project Synthesis final report.* To be published by the National Science Foundation.

JENKINS, E. (1979). *From Armstrong to Nuffield. Studies in twentieth-century science education in England and Wales.* London, John Murray.

LAYTON, D. (1981). The schooling of science in England. In: MACLEOD, R. & COLLINS, P. (eds.) *The Parliament of Science. The British Association for the Advancement of Science*, Science Reviews Ltd.

LAYTON, D. (1982). Science education and values education – an essential tension? In: HEAD, J. (ed.) *Science for the Citizen*, London, The British Council.

ORPWOOD, G. (1980). Deliberative inquiry into Canadian science education. *Journal of Curriculum Studies*, **12**, 363-364.

ROBERTS, D. & RUSSELL, T. (1975). An alternative approach to science education research: drawing from philosophical analysis to examine practice. *Curriculum Theory Network*, 5 (2), 107-125.

ROBERTS, D. (1978). Curriculum emphases in science education: alternate views about the role of science in schools. In: *Education in science and science in education* (A collection of papers in honour of Fletcher G. Watson).

STAKE, R. & EASLEY, J. *et al.* (1978). *Case studies in science education*, Urbana, Illinois. Centre for Instructional Research and Curriculum Evaluation, University of Illinois.

WARING, M. (1979). *Social pressures and curriculum innovation. A study of the Nuffield Foundation Science Teaching Project*, London, Methuen.

YAGER, R.E. (1981). *Analysis of current accomplishments and needs in science education.* ERIC/SMEAC Clearinghouse for Science, Mathematics and Environmental Education, Columbus, Ohio: The Ohio State University.

PUBLICATIONS RECEIVED

V. Daniel Ochs (ed.) *Improving Practices in Middle School Science. 1981 AETS Yearbook.*
ERIC Clearinghouse for Science, Mathematics and Environmental Education. The Ohio State University. 1981. $8.50.

National Science Foundation
What are the needs in Pre-College Science, Mathematics and Social Science Education. Views from the field.
National Science Foundation, Office of Program Integration, Directorate for Science Education. SE 80-9. 1980.

Science Policy Studies and Documents No. 49
World Directory of research projects, studies and courses in science and technology policy.
UNESCO, Paris. 1981.

UNESCO Handbook for science teachers.
1980. pp.208. $14.95.
Heinemann Educational Books, London, and Unipub, New York.

C. A. Gregory *Calculators in the Elementary Mathematics Curriculum. An annotated bibliography.*
Centre for Studies in Science Education, University of Leeds, Leeds LS2 9JT. 1981. pp. 94. £2.25

RESEARCH IN SCIENCE EDUCATION

Volume 10 of *Research in Science Education*, the annual publication of the Australian Science Education Research Association, is available, A$10, from:

Professor Colin Power, A.S.E.R.A. Executive Secretary,
School of Education,
Flinders University, Bedford Park, 5042,
South Australia, Australia.

Contents:

Robert Karplus: *Teaching for the Development of Reasoning.*

Roger Osborne: *Some Aspects of the Students' View of the World.*

Ross Tasker: *Some Aspects of the Students' View of* **Doing** *Science.*

Peter J. Fensham: *A Research Base for New Objectives of Science Teaching.*

R. F. Gunstone and R.T. White: *A Matter of Gravity.*

Richard F. Gustone: *Word Association and the Description of Cognitive Structure.*

J. Deacon and R. Bamford: *Problem Solving Applied to a Direct Current Circuit in a Physics Examination.*

J. Dekkers and T. Johnston: *Cognitive Preference and Cognitive Style: Their Utilisation in the Design of Learning Experiences in Science Instruction for Nurses.*

David J. Symington: *Primary School Teachers' Knowledge of Science and its Effect on Choice Between Alternative Verbal Behaviours.*

Colin F. Gauld: *Subject-Oriented Test Construction.*

A. J. D. Blake and D.M. Hill: *The Understanding in Science Test as a Measure of Piagetian Level of Intellectual Development.*

J. E. Butler, W. F. Beasley, D. Buckley and L. Endean: *Pupil Task Involvement in Secondary Science Classrooms.*

Adrian Fordham: *Student Intrinsic Motivation, Science Teaching Practice and Student Learning.*

R. G. Hacker and J. N. Miles: *A Study of Science Teaching Processes and their Implications for Science Education Policy Formation.*

John Ainley: *Background Aptitude and School Factors Related to Achievement in Year 12 Science Subjects.*

Anne Eggins: *The Interaction Between Structure and Learning Materials and the Personality of Learners.*

Abdul G. Khan: *Inter-relationships of Aptitude and Cognitive Achievement Measures in an Audio-Tutorial Introductory College Biology Course.*

R. Hirst, C. Malcolm and J. Owen: *An Example of Evaluation in the Development of a Tertiary Physics Programme.*

R.A. Schibeci: *Science Teachers and Science Related Attitudes.*

Days of Judgement

Science, Examinations and the Codification
of Knowledge in Victorian Britain

Edited by Roy MacLeod

"Public examinations were one of the great discoveries of nineteenth century Englishmen". This discovery rested in large measure on the belief that competitive, open (and usually written) examinations would eventually remove the undesirable consequences of unregulated favouritism and would, if universally extended, have a salutary influence on society generally.

"A fascinating, erudite book, the result of a great deal of very careful research".

J.W.

ISBN 090 5484 150. £18.50 casebound (post free)
U.S. $35.00

NAFFERTON BOOKS
2 RAILWAY COTTAGES
WANSFORD ROAD
DRIFFIELD
N. HUMBERSIDE
GT. BRITAIN

Tel: (0377) 46861

Information for contributors

As an instrument of research and criticism, it is not the intention of *Studies in Science Education* to compete with existing journals, but to complement them by providing reviews of research on specific aspects of science education and by drawing together, in analytical surveys, recent contributions which may be published in widely scattered sources. It will publish work which reflects a wide variety of standpoints, including those of administration, curriculum, history, linguistics, philosophy, politics, psychology and sociology.

Whereas most of the articles will be invited, the editor will welcome approaches from prospective authors who feel that their research experience qualifies them to write a comprehensive review of studies in a particular field. A document, *Notes for Contributors*, is available, on request, from the Honorary Editor, Studies in Science Education, Centre for Studies in Science Education, The University, Leeds LS2 9JT.

Books for review

A limited number of books of special concern to those involved in research in the field of science education will be reviewed in each volume. Books for review should be sent to Professor D. Layton, Centre for Studies in Science Education, The University, Leeds LS2 9JT, England.

The Centre for Studies in Science Education
University of Leeds

The Centre for Studies in Science Education was formally established on 1st March 1970. Apart from a course of initial training for graduate teachers of science and mathematics, suitably qualified students may prepare for the following higher degrees: M.A., M.Ed., M.Phil., Ph.D. (Inquiries should be directed to Professor D. Layton, Centre for Studies in Science Education, The University, Leeds LS2 9JT). There are well-developed research interests in a number of fields including: children's understanding of scientific and mathematical concepts; the social history and politics of science education; computer-based learning of science and mathematics; the diffusion and adoption of curriculum innovations; the national assessment of children's scientific attainments.

STUDIES IN SCIENCE EDUCATION VOLUME 9 1982

CONTENTS

Articles

Mary C. McConnell	*Teaching about Science, Technology and Society at the secondary school level in the United States. An educational dilemma for the 1980s.*
P. James Gaskell	*Science, Technology and Society: Issues for Science Teachers.*
Dorothy Nelkin	*Science and Technology Policy and the Democratic Process.*
Catherine A. Manthorpe	*Men's Science, Women's Science or Science? Some issues related to the study of girls' science education.*
Donna M. Kaminski	*Girls and Mathematics and Science. An annotated bibliography of British Work (1970-1981).*
R.M. Garrett I.F. Roberts	*Demonstration versus Small Group Practical Work in Science Education. A critical review of studies since 1900.*

Research Notes

Th. Wubbels, H.A. Créton, H.P. Hooymayers, A.J.C.D. Holvast.	*Training teachers to cope with the 'Reality Shock'.*

Supplementary list of theses and dissertations submitted for higher degrees in British Universities, 1979-80.

Research information

Review

Gaalen Erickson	*Policy, perceptions and practice. New directions for science education.*

STUDIES IN SCIENCE EDUCATION

is an international review of research for all who are interested in the educational dimensions of science. It is not intended to compete with existing journals, but to complement them by providing reviews of research on specific aspects of science education and by drawing together, in analytical surveys, recent contributions which may be published in widely scattered sources. Its editorial policy is to encourage work which reflects a wide variety of viewpoints, including those of anthropology, curriculum, history, linguistics, philosophy, politics, psychology and sociology.

Annual Subscription 1982
USA $11 plus $1 postage
UK £4.50 plus 50p postage

ISSN 0305 7267

Nafferton Books, Railway Cottages, Wansford Road, Driffield, N. Humberside, United Kingdom.